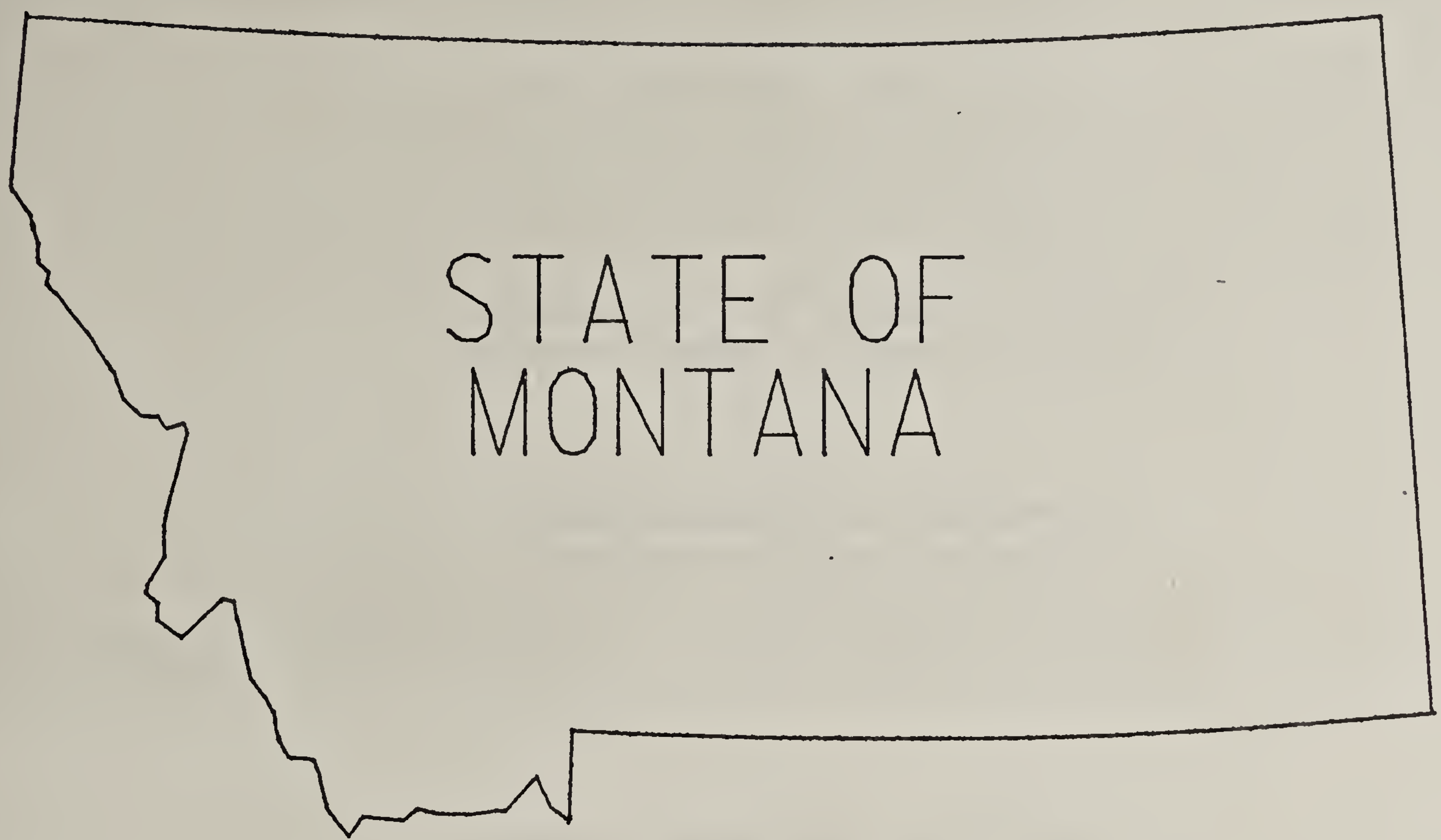
DEPARTMENT OF HIGHWAYS



Evaluation of Test Methods to Predict Moisture Damage in Asphalt Concrete

by

Bradley Bruce, P.E., Supervisor
Bituminous Mix Design Section

Montana Department of Highways
Materials Bureau
2701 Prospect Avenue
Helena, Montana 59620

Submitted for Contract
no DTFH61-88-C-00084
To U.S. Dept. of Transportation

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16. Abstract

The actual moisture suceptibility of 10 bituminous mixtures placed in the field was compared to the moisture suceptibility that was predicted during the laboratory evaluation of the same asphalt aggregate mixture as the mix design was performed. Laboratory mixtures were evaluated using the modified Lottman procedure and the Root Tunnicliff procedure in addition to routine moisture suceptibility testing which includes immersion compression testing.

After two years in the field, cores were taken and the condition of the core and its present suceptibility to moisture damage was determined by performing modified Lottman and Root Tunnicliff testing. A feature of part of the evaluation process was the use of the ACMODAS program to predict the remaining service life of the plant mix cores.

The validity of the process of predicting remaining pavement service using Modified Lottman or Root Tunnicliff testing will not be known until the pavements in the study reach their terminal distress and require repair or rehabilitation. The comparisions of modified Lottman, Root Tunnicliff and Immersion Compression testing data of the same mixtures may be of interest to some people.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

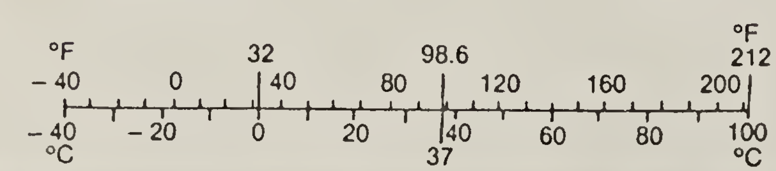
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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BACKGROUND

The State of Montana has been aware of the susceptibility to moisture damage of some bituminous mixtures for many years. We commonly used hydrated lime to improve these mixtures. We used antistrips such as 0.5% Acra 500 to decrease the stripping of asphalt from bituminous mixtures years ago. Later, when this additive was discontinued, we tested mixtures with newer antistrips. We found that the effectiveness of the antistripping agents decreases with the amount of time the treated asphalt is stored in a hot tank. After designing mixtures with antistrips, we encountered difficulty when the antistrip used did not sufficiently improve the mixture. We discontinued the use of antistrips for construction of plant mix pavements, although it still may be used with maintenance mixes. The use of antistrips has suffered in Montana due to the unavailability of a static inline system to provide uniform blending.

Montana has developed its own test to visually assess stripping. The details of this test are described in the appendix material. Essentially, aggregate is mixed with hot asphalt, "cured", and then immersed in water. After a 24-hour immersion in water, the aggregate is vigorously agitated and dried. The coverage of asphalt remaining on the aggregate is reported.

A test we used to qualify the stripping potential with numerical data is the immersion compression test (AASHTO T-165). It was used in our laboratory as early as the mid-1950's. We have used the test for (1)

evaluating aggregate sources and, (2) determining -- during design -- the additive to be incorporated in specific bituminous mixtures. When immersion compression testing has indicated a potential for stripping, the addition of hydrated lime has produced significant improvements in many of the mixtures. As a result, we have frequently used hydrated lime.

On the whole, the utilization of hydrated lime in bituminous mixtures has served us well. In addition, to acting as a bonding agent and increasing the immersion compression; hydrated lime increases adhesion, reduces the plasticity index, reduces volume swell and increases Marshall stability.

The cost of hydrated lime and its incorporation into bituminous mixtures has increased to where we are obligated to make an accurate determination of when hydrated lime is effective and when its use is an unnecessary expense.

To insure that we were up to date in this area, we participated in NCHRP 4-8(3)1 the moisture induced damage study that was principally the work of Dr. Robert Lottman. This study was directed to the evaluation of bituminous mixtures using E Modulus equipment and indirect tensile loading of specimens to failure.

The objective was to predict pavement moisture damage susceptibility by determining the physical properties of test specimens before and after a conditioning process intended to simulate environmental conditions.

During that study, we concluded that the E Modulus test was questionable, but tensile loading of samples had potential, as did resilient modulus testing under very controlled conditions. When the study was completed, the data did not show that any of the test alternatives were superior to the best of their current stage of development. We continued to determine moisture damage susceptibility using the immersion compression test. An added advantage to continuing to use the immersion compression test to determine moisture susceptibility of bituminous mixtures is, we have extensive files of test data and field performance of bituminous mixtures for this method. We based our acceptance of bituminous mixture, immersion compression ratios on the general rule that 59% retained strength or greater was a satisfactory bituminous mixture. We did not formally use the total dry strength of a mixture, but bituminous mixtures with less than 150 psi were suspect even with a "good" retained strength ratio. In 1986, we revised how we evaluated aggregate for moisture damage susceptibility and established 70% or greater retained strength as a satisfactory bituminous mixture.

Bituminous mixtures with this minimum ratio were not used very often. Our objective was to produce the best possible bituminous mixture. If we achieved an increase of 15% in immersion compression by using hydrated lime, we added it to the design recommendations. This usually increased immersion compression ratios of the designed mix to the 80% range.

PROGRAM INITIATION

In 1986, our Federal Highway, Region 8, Administrators started to advance the idea of using Root-Tunnicliff and Modified Lottman bituminous mixture evaluation testing to assess moisture susceptibility. In compliance, we added Modified Lottman testing to our proposed surfacing testing and to our mix design testing as a "trial test". We compared the data that was developed with what the immersion compression, adhesion, and other aggregate and mixture tests indicated.

Comparison of the interpretation of data from a new test with the interpretation of data from familiar tests has limited usefulness if the reliability of the familiar test is being questioned. The true basis for the assessment of a bituminous mixture is how it performs in the environment in the field; and does the behavior of the bituminous mixture follow the predictions that were made on the basis of the testing that was performed.

At this stage in the development process of determining moisture damage susceptibility of bituminous mixtures, the Federal Highway Administration sent us a solicitation for participation in an implementation project. The plan of this project to have four selected states complete a study evaluation of asphalt stripping tests. As we were already engaged in a program in-house, that paralleled the objectives we felt we would benefit by participating in the program. We submitted a proposal that required us to select a project from each of our eleven districts. This selection would provide us with a diverse

sampling of both geographic climatic areas and aggregate sources. We planned to evaluate the bituminous mixtures we designed by using Modified Lottman and Root-Tunnicliff testing in addition to our standard tests. Bituminous mixtures that required hydrated lime for either immersion compression or Marshall stability requirements were tested both using hydrated lime and without hydrated lime in the laboratory. This is because the hydrated lime is considered an inhibitor of stripping and other moisture damage susceptibility effects. However, with these bituminous mixtures, no plant mix without hydrated lime was placed in the field.

PROJECT SCOPE

We were awarded a two-year contract for the study we proposed. The contract required us to conduct an evaluation of Modified Lottman and/or Root-Tunnicliff test methods to predict bituminous mixture susceptibility. We had determined we would conduct bituminous mixture evaluation following T283-85 and input the data into the ACMODAS program on selected representative projects in 1987. The ACMODAS program is the PC program written by Dr. Lottman to interpret the data of the T283-85 test procedure and to calculate a life expectancy for a pavement.

Since the Root-Tunnicliff procedure provides quicker results and a freeze-thaw cycle is not necessary, we decided to also include this test in the evaluation.

There is a tendency when evaluating a new procedure to reference it to the current method. In this study, we adhered to this practice for our initial analysis of the test data. For each test section we used AASHTO T165 immersion compression testing to determine bituminous mixture moisture damage susceptibility following procedure 7.1.3 to condition the samples to develop an initial assessment of the bituminous mixtures. These procedures are described in the attachments as MT323 and MT324. Each result of the experimental tests was compared to this "standard". As a more conclusive method of evaluating data from the proposed test procedures, we planned to core the roadway after two years and to test the cores using the Modified Lottman and Root-Tunnicliff testing. The initial prediction of pavement life expectancy made after testing laboratory samples could be compared to the subsequent prediction made after testing the same bituminous mixture two years later using field cores. We thought the consistency of the prediction and the condition of the core, after two years, would provide a reasonably reliable basis for recognizing if the life cycle was accurately predicted by the initial testing.

Montana is a very large and geographically diverse State. We felt if we selected a minimum of two projects from each of the five districts we would have data from representative aggregate sources, and have bituminous mixture in areas extending throughout the State. For our final list of projects, we had eleven pavement sections to evaluate.

For moisture damage susceptible bituminous mixtures that we detect by immersion compression testing, we add 1.4% hydrated lime by total weight of mix. Low immersion compression values are usually increased by 20%

and average range immersion compression values are increased by 10%. We were very interested in learning how the pavement properties are affected by the addition of hydrated lime as determined by Modified Lottman and Root-Tunnicliff laboratory testing of bituminous mixtures.

After completing the Modified Lottman and Root-Tunnicliff test procedures, we planned to use the retained strength ratio (wet strength divided by dry strength X 100) for an "intuitive" assessment of the properties of the mixtures. With +70% retained strength, a bituminous mixture is normally sound and able to withstand saturation and other adverse weathering conditions. With 50%-60% retained strength, the mixture has some moisture damage susceptibility and requires the protection of using hydrated lime or some other system to retard moisture penetration into the bituminous mixture. If the retained strength ratios are less than 50%, the mixture is susceptible to moisture damage and the pavement life will be less than for an aggregate asphalt mixture that is not as susceptible.

We also planned to input the data into the ACMODAS program developed by Dr. Robert Lottman at the University of Idaho. The test data generated in this project under the T-283 and Root-Tunnicliff procedures will be processed using the ACMODAS computer program developed under the NCHRP 4-8(3)1 Project. This program provides for a calculation of the susceptibility of a mixture to moisture damage and a predicted longevity of the resulting bituminous pavement. The computer program requires both the test data and the conditions of anticipated field exposure as input variables. This data processing will be performed using an IBM-PC

computer currently available in the Materials Bureau Laboratory. Comparing the life predictions from the original laboratory bituminous mixture and the predicted life remaining from the field cores, we could assess the value of the prediction. Did the pavement life remaining determination, made for an aged and environmentally exposed pavement sample, validate the pavement life projection made with the initial laboratory bituminous mixtures?

Project Implementation

In 1987, we reviewed the projects that were scheduled to be paved. We selected a diverse sampling of geographic/climatic areas and multiple aggregate sources. We planned for at least one project from each of our districts and areas.

Extra aggregate was to be submitted when the aggregate from the projects was submitted for mix design. In addition to performing the mix design which includes immersion compression testing, we planned to complete Modified Lottman and Root-Tunnicliff testing for these aggregate sources. For fabrication of the test specimens, we would use the same asphalts, additive (if any), contractor's target grading, and specified aggregate bin proportions as used in the original mix design.

As our program is focused upon adding one of the newer test methods to our design procedure, the comparison to the immersion compression test results will be very important. The test method that most accurately

predicts moisture susceptibility will be considered for incorporation into our routine design procedures. If either the Modified Lottman or Root-Tunnicliff test procedures indicate a significant improvement in predictive capabilities is possible, we would perform that test to supplement the immersion compression test for a few years, to build our experience and data base before starting to rely on it exclusively for moisture damage susceptibility determinations.

TEST PROJECTS

We selected the 11 test projects to represent a diversity of conditions and quality of materials. If a test procedure could be used to successfully predict pavement service with this wide variety of aggregates and conditions, it would be worth adopting.

In the course of the construction year, we procured aggregate for 10 projects and generated Marshall, immersion compression, Lottman, and Root-Tunnicliff data for each. Five of the projects selected for this study required hydrated lime to be added to the bituminous mixture. With these projects, additional laboratory specimens both with and without hydrated lime were prepared for testing using the Modified Lottman and Root-Tunnicliff procedures. The additive, no additive testing would allow us to assess the stripping potential of the bituminous mixtures and to compare these results with the initial conclusions made after immersion compression testing of the same aggregate samples. One project we intended to evaluate was dropped when

the aggregate supply was "reclaimed" immediately after the paving was completed. We did not have enough retained aggregate to complete all of the planned testing.

We established base line values using all three moisture damage susceptibility systems and pavement life predictions with Lottman and Root-Tunnicliff testing.

Two years later we went out and cored each of the study projects. We tested the cores and determined Modified Lottman values, Root-Tunnicliff values and again processed this information using the ACMODAS program.

We compared the initial data, the data in two years time and the apparent correlation obtained from the two data sets. We expected longevity predictions at two years to compare by some ratio to initial data. We also thought there might be some relationship between the different test systems. When we did not find definite relationships we studied compaction, aggregate grading, and % AC to determine if the moisture damage susceptibility could be influenced by these factors. The following list is our test project table. The mix design for each of these projects is in the appendix. Although we are primarily interested in general data comparison and correlation, not specific projects, all analysis and discussion is referenced to a project name in addition to the test group numbers identified in this table.

TABLE I. PROJECT/TEST GROUPS

Test Group	Project Name	Project Number
1	Seeley Lake-Inez	RTF 83-1(4)15
2	Ulm-South	RS 330-1(7)0
3	Helena-West	RTF-BRF 8-2(15)34
3a	Helena-West (Hydrated Lime)	RTF-BRF 8-2(15)34
4	Kila-West	F-BRF-HES 1-2(37)99
4a	Kila-West (Hydrated Lime)	F-BRF-HES 1-2(37)99
5	Nashua-North	RS 438-1(4)0
6	Bridger-Fromberg	F-BRF 4-1(5)26
6a	Bridger-Fromberg (Hydrated Lime)	F-BRF 4-1(5)26
7	Three Forks - North	F-HES 8-4(11)99
8	Big Sandy	RRS 10-2(14)71
8a	Sandy (Hydrated Lime)	RRS 10-2(14)71
9	Klein - South	F-HES 16-2(3)29
9a	Klein - South (Hydrated Lime)	F-HES 16-2(3)29
10	Miles City - Northwest	F-HES 18-1(2)1

The test data that was developed is listed. For the classification of the test groups columns 5, 6 and 7, we classed 70% or greater retained strength as good, 70%-55% retained strength as suspect and less than 55% as bad.

TABLE 2. GROUP CLASSIFICATION

Group No.	IC %	Lottman %	Root-Tunnicliff %	Good	Suspect	Bad
1	67.8	65.8	81.4	RT	IC,ML	
2	67.9	78.9	80.0	ML,RT	IC	
3	68.6	52.4	63.6		IC,RT	ML
3a	75.8	58.0	55.3	IC	ML,RT	
4	59.3	51.3	41.5		IC	ML,RT
4a	78.8	79.2	72.9	IC,ML,RT		
5	77.3	81.8	50.6	IC,ML		RT
6	41.5	88.0	44.3	ML		IC,RT
6a	64.0	76.0	67.2	ML	IC,RT	
7	97.1	65.1	67.2	IC	ML,MT	
8	54.5	57.2	51.8		ML	IC,RT
8a	83.3	61.8	80.3	IC,RT	ML	
9	64.5	62.0	69.1		IC,ML,RT	
9a	81.3	79.5	79.0	IC,ML,RT		
10	88.5	78.8	94.2	IC,ML,RT		

From this grouping, we see that moisture damage susceptibility is significant according to some test for six of the sample groups if the borderline group 3a is counted.

Moisture damage susceptibility is probable or the mixture is suspect for six additional sample groups. Thus, there are only three aggregate groups for which none of the moisture damage susceptibility detection tests indicate that the mixture is susceptible to moisture damage. Of these three groups, two of them are mixtures to which 1.4% hydrated lime was added. Only group ten aggregate exhibits a lack of sensitivity to moisture damage without an additive. Conversely, of the ten groups of aggregate evaluated not one group tested universally bad by all three tests being considered. Three of the five mixes where hydrated lime was used for the mix design and in the construction showed "bad" moisture damage susceptibility without addition of the hydrated lime. Into the bituminous mixture these are group 4, group 6 and group 8. For groups 3 and 9, the other two groups where hydrated lime was used the mixes that were suspect without the hydrated lime improved in at least one test parameter when hydrated lime was added to the bituminous mixture.

A project by project review of the moisture damage susceptibility data for each project was performed. In this review note the following:

1) Referenced, Montana Test Methods (MT), are in the back of this report.
2) Sieve sizes to describe aggregate gradations are U.S. standard sieve designations.
3) Immersion compression test samples are fabricated according to MT323 and tested according to MT324. This is similar to AASHTO T165 and T167.

Terms that are referred to in the project by project review are as follows:

Absorption - water absorption of aggregate determined using procedures MT204 and MT205.

Adhesion - the percentage of asphalt adhering to a selected sample of aggregate after the aggregate is coated, soaked 24-hours in distilled water, agitated in a paint shaker and visually assessed following procedure MT309.

Fracture - the percentage of aggregate that has at least one mechanically fractured face, which is determined following MT217.

VMA - Abbreviation for Voids in Mineral Aggregate.

Volume Swell - The percentage of volume change of -10M aggregate after saturating with water for a 24-hour period. Asphalt is used to bond the aggregate to enable measuring the volume.

PROJECT REVIEW

1) Seeley Lake - This mix design was performed in September 1987 with a good aggregate that was more absorptive (2.19% absorption) than most. The adhesion was 80%, the immersion compression was 67.8% and the volume swell of the -10M was 1.5% the fracture was 80% and

the VMA was 14.0%. Marshall stabilities were 1900 pounds. The Lottman retained strength ratio was 66% and the Root-Tunnicliff retained strength ratio was 81%. No additive was recommended. The cores now show 80% adhesion. The Lottman and Root-Tunnicliff values on the cores are both much less than the mix design; 37.0% and 48% respectively. The predicted life of plant mix evaluated during the mix design was 17-18 years. The prediction from field cores two years later was approximately six years. The density of a field core (2.243) was much less than the mix design density of 2.306, so this may be a significant factor.

2) Ulm - South - This project was from another district and another geographic area. The mix design was performed September 2, 1987. This was another good aggregate that was moderately absorptive (1.59% absorption). The adhesion was 80%, the immersion compression was 67.9% and the volume swell of the -10M aggregate was 2.8%. The fracture was 78% and the VMA was 14.0.

Marshall stabilities were 2000 pounds.

The Lottman and Root-Tunnicliff retained strength ratios of the mix design were 79% and 80% respectively. The predicted life of the tested mix design samples with no additive was approximately 15 years with either the Lottman or the Root-Tunnicliff testing. The predictions of the pavement life from testing the field cores taken two years later were 8-10 years, so the deterioration is apparently occurring at a higher rate than estimated in the calculations of

pavement service life. The density of the field cores is 2.357 compared to a density of design of 2.341, so density was achieved and high voids are not accelerating the deterioration.

3) Helena - West - This roadway mix design was performed December 1987 with a good moderately, absortive aggregate (1.51% absorbtion). Hydrated lime was added to increase the Marshall stability but this also influenced immersion compression data, adhesion, volume swell and other mixture properties. As designed, the adhesion was 80%, the volume swell was 5.4%, fracture was 72% and the VMA was 16.2%.

The Marshall stabilities were 2160 pounds and the immersion compression was 76% retained strength. The mix design Modified Lottman testing indicated a 13-year service life and the Root-Tunnicliff testing indicated a 20-year service life. Modified Lottman and Root-Tunnicliff retained strengths were 55-58%. Cores taken two years later indicated 12 years of remaining service life using Modified Lottman test data and 6.6 years of remaining service life. Modified Lottman and Root-Tunnicliff retained strength ratios had declined to 48%. Obviously, one of the procedures is not generating the correct prediction. The density of a field core was approximately the same as the density of the mix compacted in the lab; 2.32 for the mix design and 2.306 for the field core. Voids are not thought to be a factor in this possibly deteriorating plant mix.

4) Kila - E & W - This mix design was performed November 1987, with a good, moderately absorptive aggregate (1.65% absorption). Hydrated lime was added to increase the immersion compression retained strength, but this also influenced adhesion, Marshall data and other mixture properties. As designed, the adhesion was 85%, the volume swell was 3.2%, fracture was 70% and VMA was 13.8%.

The Marshall stabilities were 2400 pounds and the immersion compression retained strength was 79%.

The mix design Modified Lottman testing indicated that the mix would provide more than 30 years of service. The Root-Tunnicliff testing indicated 20 years of service, still an acceptable service life. The retained strength of Modified Lottman samples was 79% and of Root-Tunnicliff samples was 73%. Cores taken two years later and tested for Modified Lottman data indicated 6.6 years service could be obtained. Root-Tunnicliff testing indicted 8.0 years of service could be expected. Retained strength ratios were 57% for Modified Lottman testing and 65% for Root-Tunnicliff testing. This is a major decrease in life service expectancy. The mix design density of 2.377 is slightly greater than the 2.365 of the field cores. Compaction differences do not appear to be a significant factor in these major changes of predicted service life for this pavement. This data of the mix design and field cores differs an abnormal amount. Some unidentified variable may be affecting this mixture.

5) Nashua - North - This mix design was performed in June 1987 with a good aggregate with 1.03% absorption. The adhesion was 75%, the immersion compression retained strength was 77.3% and the volume swell of the -10M was 4.2%. Fracture was 86% and the VMA was 15.3. Marshall stabilities averaging 1273 pounds were the only indications this was not a good aggregate for bituminous mixtures. The Lottman was 81.8% and the Root-Tunnicliff ratio was 50.6%. No additive was recommended. The cores now show 70% adhesion. The Lottman and Tunnicliff retained strength ratios are not the same; 67.6% for the Modified Lottman, 109.6% for the Root-Tunnicliff test. The predicted life of plant mix evaluated during the mix design was 26.7 years by Lottman testing and 11.1 years by Root-Tunnicliff testing. This relationship is reversed by the field core predictions taken two years later. Predictions based on Modified Lottman data from cores are for a 9.8 year service life. Predictions based on cores by Root-Tunnicliff testing is that the pavement life expectancy is 25.8 years; a 14.7 year increase from the testing during the mix design. The Modified Lottman retained strength ratio was 67.6% and the Root-Tunnicliff retained strength ratio was 110%. The density of a field core (2.368) was greater than the mix design density of 2.330. We decided this was not a significant factor in this reversal of life cycle expectancy, because even though the Root-Tunnicliff test values increased with the density increase, the Modified Lottman predicted life expectancy decreased.

6) Bridger - Fromberg - The mix design was performed August 12, 1987. This was another good aggregate that was moderately absorptive, (1.43% absorption). Hydrated lime was added to increase the immersion retained strength compression and the Marshall stability. With the hydrated lime, the adhesion was 85%, the immersion compression was 64% and the volume swell of the -10M aggregate was 2.2%. The fracture was 74% and the VMA was 13.9.

With Marshall stabilities of 1960 pounds, the only indication that this was not a good bituminous mixture using our conventional criteria was the lower than normal immersion compression ratio.

The Lottman and Root-Tunnicliff retained strength ratios of the mix design were 76% and 67% respectively. The predicted life of the tested mix design samples was 14.4 years with the Lottman and the Root-Tunnicliff testing. The predictions of the pavement life from testing the field cores taken two years later were 8-10 years by the Lottman test and 39 years by the Root-Tunnicliff test. Surprisingly the retained strength ratios were close, 79% for the Modified Lottman testing and 82% for the Root-Tunnicliff testing. This major disparity will help to determine the validity of one test method when the life cycle matches the prediction. With this project, the density of the field cores is 2.357 compared to a density of design of 2.378. Since density was achieved, high voids are not accelerating the deterioration.

7) Three Forks - North - This roadway mix design was performed in September 1987 with an aggregate having a 0.95% absorption. No additive was used for this bituminous mixture. As designed, the adhesion was 75%, the volume swell was 3.3%, fracture was 80% and the VMA was 14.8%.

The Marshall stabilities were 1768 pounds and the immersion compression was 97.1% retained strength. The mix design Modified Lottman data indicated 5.2 years and the Root-Tunnicliff data indicated 14.4 years of service were available. Retained strength ratios of these two tests were 65%-67%. Cores taken two years later tested for Modified Lottman indicated 5.2 years of service and Root-Tunnicliff testing indicated 7.6 years of service. Retained strength ratios were 57% for Modified Lottman testing and 60% for Root-Tunnicliff testing. These two procedures are essentially in agreement on a prediction of the longevity of this pavement from the field cores. The density of a field core was slightly greater than the density of the mix compacted in the lab; 2.363 for the mix design and 2.38 for the field core, so compaction is not believed to be a negative factor.

8) Big Sandy - This mix design was performed in September 1987, with a good, moderately absorptive aggregate with 1.65% absorption. Hydrated lime was added to increase the immersion compression retained strength, but this also influenced adhesion, Marshall data and other mixture properties. As designed, the adhesion was 85%, the volume swell was 5.1%, fracture was 81% and the VMA was 14.2%.

The Marshall stabilities were 2000 pounds and the immersion compression was 83.3% retained strength with the hydrated lime.

The mix design Modified Lottman testing indicated that the mix would provide 20 years of service (80.3% retained strength). The Root-Tunnicliff testing indicated 9.4 years of service (61.8% retained strength).

Cores taken two years later and tested for Modified Lottman data indicated 9.4 years of service remained and Root-Tunnicliff testing indicted 7.3 years of service could be expected. Retained strength ratios with both procedures were approximately 72%. Core data is relatively consistent for the two test methods. The mix design density of 2.338 is somewhat more than the 2.309 density of the field cores. The level of compaction may be a factor in reduction of predicted life service when comparing the results of testing the mix design samples and the field core samples.

9) Klein - South - This roadway mix design was performed August 5, 1987 with a good moderately absorptive aggregate with an absorption of 1.51%. Hydrated lime was added to increase the Marshall stability and the immersion compression retained strength, but this also influenced adhesion, volume swell and other mixture properties. As designed, the adhesion was 85%, the volume swell was 1.4%, the fracture was 83% and the VMA was 14.4%.

The Marshall stabilities were 1880 pounds and the immersion compression was 81% retained strength. The mix design Modified Lottman testing indicated 11.9 years of service before failure and the Root-Tunnicliff test data indicated 10.8 years. Both tests yielded 79% retained strength of mix design samples tested. Cores taken two years later tested for Modified Lottman indicated 27 years of service and Root-Tunnicliff testing indicated 9.7 years. Retained strengths of cores were 110% for Modified Lottman testing and 76% for Root-Tunnicliff testing. One of the procedures is not generating the correct prediction. The density of a field core was less than the density of the mix compacted in the lab, 2.363 for the mix design; compared to 2.316 for the field core. The increase of pavement life projected from the second Modified Lottman testing is opposite to what the lesser density of plant mix would produce.

10) Miles City - NW - This mix design was performed April 24, 1987 with a good aggregate that had 1.78% absorption. No additive was required. The adhesion was 75%, the immersion compression retained strength was 88.5% and the volume swell of the -10M was 1.8%. Fracture was 89% and the VMA was 15.6%. Marshall stabilities were 2000 pounds. The Lottman was 79% and the Root-Tunnicliff was 94%. The cores now show 70% adhesion. The predicted life of the mix design was 16 years for the Lottman test and 21 years for the Root-Tunnicliff test. The field core predictions from cores taken two years later are 9-10 years for either test. The Modified Lottman and Root-Tunnicliff retained strengths are somewhat less, 67% and 74% respectively. The density of a field sample with a

density of 2.317 is somewhat less than the density determined during the mix design of 2.340. This rather minor difference in densities is not believed to be a significant factor in the predicted moisture damage susceptibility of these mixtures.

Conclusions and Summary of Group Review

For this project, we determined immersion compression, Modified Lottman, Root-Tunnicliff and visual stripping of 10 bituminous mixtures at the mix design stage. Two years later we took cores from the roadway and tested them for Root-Tunnicliff, Modified Lottman and visual stripping. We attempted to determine which test data taken initially at the mix design stage was most consistent with the same type of data determined by testing field cores later. After this was done, we did not have enough uniformity of predicted core condition and actual core condition to conclusively prove or refute that the test procedures evaluated could be interpreted to predict plant mix moisture damage susceptibility.

There are contradictions as to what may be expected of the pavement in service with each type of data immersion compression, Lottman and Root-Tunnicliff. Some plant mix that immersion compression data indicated will provide a useful service life was noticeably stripped within the two years between the placement of the section and when the cores were taken. Testing of pavement cores from some other projects indicated that the pavement section would exceed the service life

predicted after fabricating and testing laboratory specimens during the mix design. This uncertainty will require additional investigation of the test procedures.

Inconsistent Moisture Susceptibility Factors

We reviewed the test data for other factors that could be introducing an influence on the moisture damage susceptibility. The factor we reviewed first was compaction. It is generally accepted that low compaction of a bituminous pavement leaves voids that provide pathways for free moisture and accelerates moisture damage. The density of plant mix for the mix design was compared to the average density of the in-place plant mix. This data is tabled in the back of this report, but no correlation was found. The asphalt cement (AC) content of the mix design was also compared to the % AC extracted from core samples from each project. A comparison was made to determine how the change in % AC corresponded to the change in moisture damage susceptibility of the bituminous mixtures. This data is included in a table in the appendix, but a correlation was not made.

The gradings of the bituminous mixtures are also tabled in this report. We compared the grading used for the mix design to the grading actually extracted from the cores and determined the differences for each of the gradation sieve sizes. The differences, in most instances, were within one standard deviation. An exception was the group 7 aggregate which had 3.4% less -200M than the mix design. This apparently does not

correlate with the predictions of life cycle, no gradation - longevity correlations were made.

All of the information used to assess pavement life cycle is included in the tables in the appendix. When a review of tabled data did not show us recognizable correlations of data and apparent plant mix performance, we tried graphing the various data sets. Comparisions were made of Modified Lottman test data developed during the mix design to Modified Lottman field data from cores two years later, and Root-Tunnicliff mix design and field data in the same sequence. The graphs identify the inconsistency of the data and the lack of a pattern characteristic of a consistent relationship between the properties of the bituminous mixture and the moisture susceptibility.

Graph Set Discussion

These graphs are discussed in detail here.

1) The first set of graphs, a mix design and field data comparison, seriously disturb the idea that mix design laboratory testing can be used to predict the service life of a pavement. If the pavement life predictions were all right, the test data determined with the mix design samples would show a pavement life expectancy of two years more than the field cores. This did not occur and cores often had half or less of the life expectancy of the mix design samples. If the test methods are capable of isolating plant mix

weakness, there is a major weakness of plant mix produced by the field production for many of the mixtures studied. However, there are also occasional projects where the plant mix produced in the field is significantly better than initially predicted by the mix design. There is an alternative interpretation to the first set of graphs. If the actual environment is more severe than the factor used in the mixture fatigue life calculation, the deterioration would occur faster than predicted. This would fit the two known data points of several of the sample groups. The validity of this theory will only be proven if the roadways fail in less time than the design life in the order of the pavement life predictions that were made.

The second set of graphs, Mix Design Lottman compared to Mix Design Root-Tunnicliff, is a reasonable match on five of the projects and the data is totally at odds on the other five projects. On three of the projects where the data is not in agreement, Modified Lottman based predictions are for a longer pavement life than predictions based on Root-Tunnicliff testing. This is not what was expected. It was anticipated that the Modified Lottman test would be more severe than the Root-Tunnicliff test because the Modified Lottman conditioning process has a freeze-thaw cycle and the Root-Tunnicliff conditioning process does not. Since it is more severe and other factors were held constant for the calculations, the wet fatigue performance life predicted using Root-Tunnicliff was expected to be longer than wet fatigue performance using Modified Lottman testing. In actual testing, the longer wet

fatigue lives were predicted by the Modified Lottman testing on seven of the test groups on the mix design. This reversed with the field cores; the Root-Tunnicliff test data did indicate a longer wet fatigue life than the Modified Lottman testing did on these samples.

The third set of graphs displayed the differences between pavement life projections using Lottman data for mix design samples and field cores taken two years later. They also display the differences between pavement life projections using Root-Tunnicliff test data for mix design samples and field cores. The graphs show the improbability that Modified Lottman or Root-Tunnicliff testing of mix design samples will compare to the same test from a field core two years later. There is no way of knowing, except to wait for the pavement life cycle to end, what testing yields results that will anticipate pavement performance.

RECOMMENDATIONS

This study was intended to validate the application of Modified Lottman testing and/or Root-Tunnicliff as acceptable methods for determining the moisture damage susceptibility of bituminous mixtures. Quantifying that determination by predicting the pavement service life was tested using an ACMODAS computer program.

We were unable to verify the validity of pavement life projections by establishing how long the pavement will provide a specified level of service before repair or rehabilitation is required. This question will be finally answered by the service life of the projects evaluated. Only when the test projects have reached their terminal life will we finally be able to determine if the pavement life cycle prediction was correct and which test procedure is the most applicable to environments in Montana. A two-year program is too short to establish the accuracy of life cycle projections for bituminous pavements.

The coring evaluation and pavement monitoring of the condition of the test groups must be continued until the pavements fail.

A data deficiency occurred when cores were not obtained immediately after the pavement was placed. We have no means of assessing how much of the difference between mix design tested samples and field cores was a result of environment and how much was differences in the bituminous mixture as it was designed and after it was placed. Future analysis of

projects should require cores immediately to complement the testing performed on the laboratory samples.

Future Plans

We have started and will continue to perform Modified Lottman testing on mix designs submitted and most proposed surfacing aggregates. We are finding frequent instances where the Modified Lottman test ratios are lower than the immersion compression ratios for the same bituminous mixtures. If the pavement performance corresponds to this lower test data (failure from moisture damage susceptibility), we may implement Modified Lottman testing as a routine procedure in our mix design program.

Modified Lottman testing used with the ACMODAS program would also permit the development of regional and geographical factors to express the severity of the environment when designing mixes. The more wet/dry cycles or freeze-thaw cycles that a pavement is to be exposed to the more effort could be directed to minimizing the moisture damage susceptibility of the bituminous mixture. If pavement service life from moisture susceptibility could be calculated, design decisions could be made based on expected service and cost/benefit ratios of additives or special asphalts. The concept would be to design for the conditions and the service life. This would be more economical as we would not pay for the minimization of moisture damage susceptibility of bituminous mixtures unless it was necessary.

APPENDIX*

DATA BASE

*See TABLE OF CONTENTS for Detailed Listing

PAVEMENT LIFE PROJECTIONS

Termini	Group No.	IC Ratio%	Mix Design Lottman	Field Cores Lottman	Mix Design -vs- -Field- Comparison +/- yrs.	Mix Design Root-Tunnicliff	Field Cores Root-Tunnicliff	Mix Design -vs- -Field- Comparison +/- yrs.
Seeley Lake Inez	1	67.8	18.6 yrs	5.4 yrs	+13.2 yrs	17.4 yrs	6.6 yrs	+10.8 yrs
Ulm South No. Section	2	67.9	16.2 yrs	7.7 yrs	+8.5 yrs	14.2 yrs	9.8 yrs	+4.4 yrs
Helena - West	3	75.8	12.9 yrs	12.1 yrs	+0.8 yrs	20.1 yrs	6.6 yrs	+13.5 yrs
Kila - E. & W.	4	78.8	37.4 yrs	6.6 yrs	+30.8 yrs	19.8 yrs	8.0 yrs	+11.8 yrs
Nashua - North	5	77.3	26.7 yrs	9.8 yrs	+16.9 yrs	11.1 yrs	25.8 yrs	-14.7 yrs
Bridger - Fromberg	6	64.0	14.4 yrs	8.9 yrs	+5.5 yrs	8.9 yrs	39.1 yrs	-30.2 yrs
Three Forks - N.	7	97.0	5.2 yrs	6.0 yrs	-0.8 yrs	14.4 yrs	7.6 yrs	+6.8 yrs
Big Sandy RR Overpass	8	83.3	20.0 yrs	9.4 yrs	+10.6 yrs	9.4 yrs	7.3 yrs	+2.1 yrs
Klein - South	9	86.3	11.9 yrs	27.3 yrs	-15.4 yrs	10.8 yrs	9.7 yrs	+1.1 yrs
Miles City - N.W.	10	88.5	16.4 yrs	8.9 yrs	+7.5 yrs	21.2 yrs	9.7 yrs	+11.5 yrs

DATA TABULATION

Mix Identity	Stripping (Retained)	Lottman (psi) Dry	Lottman (psi) Wet	Root Tunnicliff (psi) Dry	Root Tunnicliff (psi) Wet	MR (psi) Lottman Dry	MR (psi) Lottman Wet	MR Lottman Dry	MR Lottman Wet
GROUP 1									
Seeley Lake - Inez		110.2	72.5	116.4	94.7	6.75x10^{+5}	3.47x10^{+5}	6.75x10^{+5}	5.23x10^{+5}
RTF 83-1(4)15 (MD)	80%	65.8%		81.4					
Seeley Lake - Inez		103.9	38.8	116.8	56.5	4.24x10^{+5}	3.36x10^{+5}	5.27x10^{+5}	4.08x10^{+5}
RTF 83-1(4)15 (core)	60%	37.3		48.4					
Differences		+6.3	+33.7	-0.4	+38.2				
(gain or loss)	+20%	+28.5		+33.0		+2.51 x	-0.11	-1.24x10^{+5}	-1.15x10^{+5}
GROUP 2									
Ulm-South		106.1	83.7	88.0	70.4	4.71x10^{+5}	3.60x10^{+5}	4.71x10^{+5}	4.08x10^{+5}
RS 330-1(7)0 (MD)	80%	78.9		80.0					
Ulm-South		105.4	56.7	91.2	61.9	3.42x10^{+5}	2.78x10^{+5}	3.88x10^{+5}	3.45x10^{+5}
RS 330-1(7)0 (core)	70%	53.8		67.9					
Differences		+0.7	+27.0	-3.2	+8.5				
(gain or loss)	+10%	+25.1			+1.21	+1.29x10^{+5}	0.82x10^{+5}	+0.83x10^{+5}	+0.63x10^{+5}
GROUP 3									
Helena-West (MD)		110.7	64.2	92.6	51.2	5.00x10^{+5}	4.06x10^{+5}	5.00x10^{+5}	3.05x10^{+5}
RTF-BRF 8-2(15)34	80%	58.0		55.3					
Helena-West (core)		99.1	48.4	107.1	52.0	4.76x10^{+5}	1.93x10^{+5}	5.12x10^{+5}	3.57x10^{+5}
RTF-BRF 8-2(15)34	40%	48.8		48.6					
Difference		+11.6	+15.8	-14.5	-0.8				
(gain or loss)	+40%	+9.2		+6.7		+0.24x10^{+5}	+2.13x10^{+5}	-0.12x10^{+5}	-0.52x10^{+5}
GROUP 4									
Kila - E & W (MD)		97.3	77.1	100.2	73.0	5.84x10^{+5}	2.99x10^{+5}	5.84x10^{+5}	3.30x10^{+5}
F-BRF-HES 1-2(37)99	85%	79.2		72.9					
Kila - E & W (core)		129.3	73.8	121.5	79.0	5.14x10^{+5}	5.31x10^{+5}	6.39x10^{+5}	5.84x10^{+5}
F-BRF-HES 1-2(37)99	75%	57.1		65.0					
Difference		-32.0	+3.3	-21.3	-6.0				
(gain or loss)	+10%	+22.1		+7.9		+0.70x10^{-5}	-2.32x10^{-5}	-0.55x10^{-5}	-2.54x10^{-5}
GROUP 5									
Nashua - North		93.6	76.6	80.8	40.9	3.67x10^{+5}	1.70x10^{+5}	3.67x10^{+5}	1.85x10^{+5}
RS 438-1(4)0 (MD)	70%	81.8		50.6					
Nashua - North		109.0	73.7	65.3	71.6	2.35x10^{+5}	2.30x10^{+5}	2.99x10^{+5}	2.94x10^{+5}
RS 438-1(4)0 (core)	30%	67.6		109.6					
Difference		-15.4	+2.9	+15.5	-30.9				
(gain or loss)	+40%	+14.2		-59.0		+1.32x10^{-5}	-0.60x10^{-5}	+0.68x10^{-5}	-1.09x10^{-5}

DATA TABULATION (Part 2 of 2)

Mix Identity	Stripping (Retained)	Lottman (psi) Dry	Lottman (psi) Wet	Root Tunnicliff (psi) Dry	Root Tunnicliff (psi) Wet	MR (psi) Lottman Dry	MR (psi) Lottman Wet	MR Lottman Dry	MR Lottman Wet
GROUP 6									
Bridger-Fromberg		126.3	96.3	115.7	77.9	$6.38\times10^{+5}$	$4.85\times10^{+5}$	$6.38\times10^{+5}$	$5.66\times10^{+5}$
F-BRF 4-1(5)26 (MD)	85%	76.2		67.3					
Bridger-Fromberg		133.0	106.2	130.7	107.0	$6.05\times10^{+5}$	$6.86\times10^{+5}$	$5.33\times10^{+5}$	$9.33\times10^{+5}$
F-BRF 4-1(5)26 (core)	80%	78.7		81.9					
Difference		-6.7	-9.9	-15.0	-29.1				
(gain or loss)	+5%	-2.5		-14.6		$+0.33\times10^{+5}$	$-2.01\times10^{+5}$	$+1.05\times10^{+5}$	$-3.67\times10^{+5}$
GROUP 7									
Three Forks - N		97.1	63.2	102.8	69.1	$3.69\times10^{+5}$	$2.27\times10^{+5}$	$3.69\times10^{+5}$	$2.28\times10^{+5}$
F-HES 8-4(11)99 (MD)	75%	65.1		67.2					
Three Forks - N		131.5	74.9	92.1	55.0	$4.54\times10^{+5}$	$5.60\times10^{+5}$	$4.09\times10^{+5}$	$3.80\times10^{+5}$
F-HES 8-4(11)99 (core)	40%	57.0		59.7					
Difference		-34.4	11.7	+10.7	+14.1				
(gain or loss)	+35%	+8.1		+7.5		$-0.85\times10^{+5}$	$-3.33\times10^{+5}$	$-0.40\times10^{+5}$	$-1.52\times10^{+5}$
GROUP 8									
Big Sandy - RR		118.0	94.8	109.1	67.4	$7.46\times10^{+5}$	$5.15\times10^{+5}$	$7.46\times10^{+5}$	$5.44\times10^{+5}$
Overpass (MD)		80.3		61.8					
RRS 10-2(14)71	85%								
Big Sandy - RR		128.3	93.1	129.6	93.3	$7.44\times10^{+5}$	$6.82\times10^{+5}$	$5.40\times10^{+5}$	$6.88\times10^{+5}$
Overpass (core)		72.6		72.0					
RRS 10-2(14)71	50%								
Difference		-10.3	+1.7	-20.5	-25.9				
(gain or loss)	+35%	+7.7		-8.2		$+.02\times10^{+5}$	$-1.67\times10^{+5}$	$+2.06\times10^{+5}$	$-1.44\times10^{+5}$
GROUP 9									
Klein - South (MD)		128.5	102.1	113.3	89.5	$4.33\times10^{+5}$	$4.17\times10^{+5}$	$4.33\times10^{+5}$	$4.44\times10^{+5}$
F-HES 16-2(3)29	85%	79.5		79.0					
Klein - South (core)		105.0	116.0	127.4	97.2	$4.72\times10^{+5}$	$4.78\times10^{+5}$	$6.16\times10^{+5}$	$6.13\times10^{+5}$
F-HES 16-2(3)29	80%	110.5		76.3					
Difference		+23.5	15.9	14.4	-7.7				
(gain or loss)	+5%	+31.0		+2.7		$+0.39\times10^{+5}$	$-0.61\times10^{+5}$	$-1.83\times10^{+5}$	$-1.69\times10^{+5}$
GROUP 10									
Miles City - NW		95.5	75.3	99.3	93.5	$2.32\times10^{+5}$	$1.78\times10^{+5}$	$2.32\times10^{+5}$	$1.76\times10^{+5}$
F-HES 18-1(2)1 (MD)	75%	78.8		94.2					
Miles City - NW		124.4	83.6	131.2	96.9	$4.52\times10^{+5}$	$4.21\times10^{+5}$	$2.93\times10^{+5}$	$3.23\times10^{+5}$
F-HES 18-1(2)1 (core)	70%	67.2		73.9					
Difference		-28.9	-8.3	-31.9	-3.4				
(gain or loss)	+5%	+11.6		+20.3		$-2.2\times10^{+5}$	$2.43\times10^{+5}$	$0.6\times10^{+5}$	$-1.57\times10^{+5}$

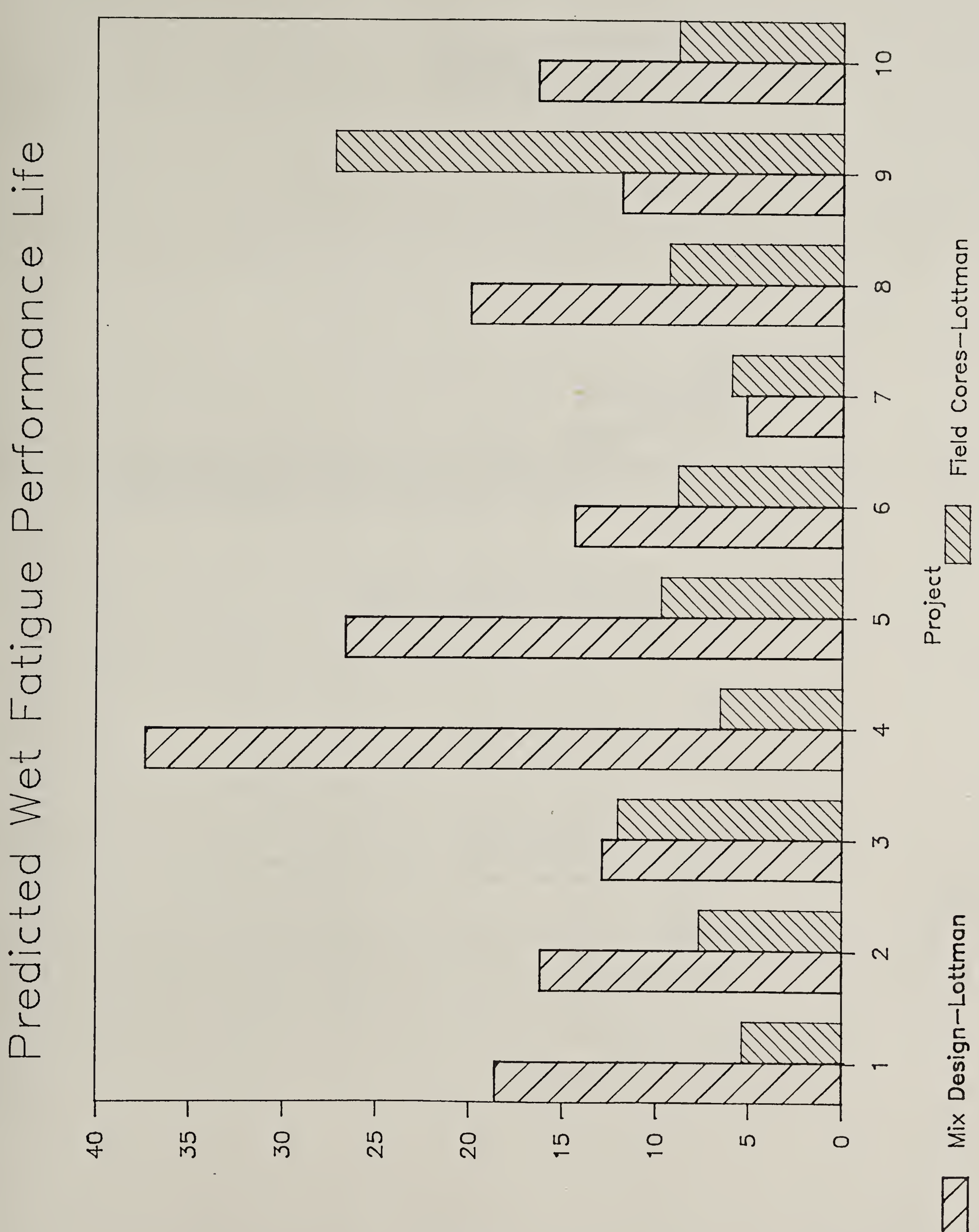
DENSITY OF BITUMINOUS MIXTURES

Mix Identity	Mix Design % AC	Mix Design Rice Gravity	Mix Design Density	Field Cores % AC	Field Cores Rice Gravity	Field Cores Density
GROUP 1						
Seeley Lake - Inez RTF 83-1(4)15	5.9	2.390	2.306	6.3	2.383	2.243
GROUP 2						
Ulm - South RS 330-1(7)0	6.2	2.424	2.341	5.9	2.459	2.357
GROUP 3						
Helena - West RTF-BRF 8-2(15)34	6.3	2.406	2.320	6.3	2.421	2.306
GROUP 4						
Kila - West F-BRF-HES 1-2(37)99	5.6	2.438	2.377	5.8	2.424	2.365
GROUP 5						
Nashua - North RS 438-1(4)0	6.1	2.413	2.330	5.9	2.418	2.368
GROUP 6						
Bridger - Fromberg F-BRF 4-1(5)26	5.7	2.462	2.378	5.6	2.452	2.357
GROUP 7						
Three Forks - North F-HES 8-4(11)99	5.6	2.446	2.363	5.3	2.433	2.383
GROUP 8						
Big Sandy RRS 10-2(14)71	5.75	2.425	2.338	6.0	2.409	2.309
GROUP 9						
Klein - South F-HES 16-2(3)29	5.6	2.450	2.363	5.4	2.456	2.316
GROUP 10						
Miles City - NW F-HES 18-1(2)1	6.5	2.380	2.294	6.2	2.385	2.306

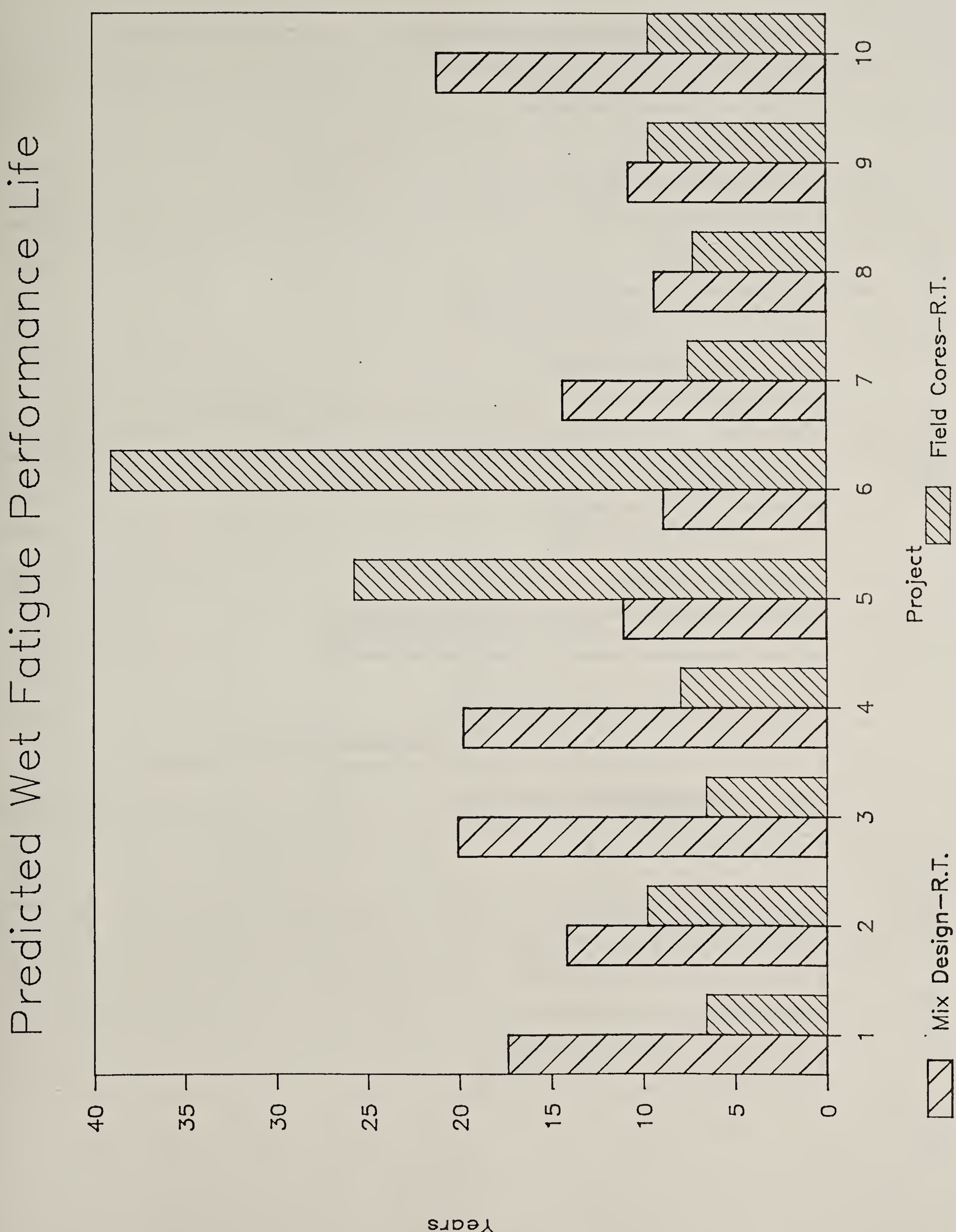
GRADINGS OF BITUMINOUS MIXTURES

Mix Identity		3/4"	1/2"	3/8"	4M	10M	40M	200M
GROUP 1								
Seeley Lake - Inez	M.D.	100	89	76	56	36	16	8.0
RTF 83-1(4)15	Cores	100	91	81	59	36	16	7.5
	Diff.	0	-2	-5	-3	0	0	+0.5
GROUP 2								
Ulm - South	M.D.	100	90	75	53	34	18	6.0
RS 330-1(7)0	Cores	100	93	73	51	35	20	5.7
	Diff.	0	-3	+2	+2	-1	+2	+0.3
GROUP 3								
Helena - West	M.D.	100	90	78	55	40	16	6.0
RTF-BRF 8-2(15)34	Cores	100	95	85	64	43	18	6.7
	Diff.	0	-5	-7	-11	-3	-2	-0.7
GROUP 4								
Kila - West	M.D.	100	86	75	53	36	16	8.0
F-BRF-HES 1-2(37)99	Cores	100	92	79	55	39	17	9.9
	Diff.	0	-6	-4	-2	-3	-1	-1.9
GROUP 5								
Nashua - North	M.D.	100	92	77	52	36	21	5.0
RS 438-1(4)0	Cores	100	92	77	54	36	21	4.7
	Diff.	0	0	0	-2	0	0	+0.3
GROUP 6								
Bridger - Fromberg	M.D.	100	90	77	53	39	18	6.0
F-BRF 4-1(5)26	Cores	100	94	80	57	41	20	5.3
	Diff.	0	-4	-3	-4	-3	-2	+0.7
GROUP 7								
Three Forks - North	M.D.	100	86	75	53	37	18	6.5
F-HES 8-4(11)99	Cores	100	82	67	47	32	18	3.1
	Diff.	0	-4	+8	+6	+5	0	+3.4
GROUP 8								
Big Sandy	M.D.	100	90	78	53	38	18	7.0
RRS 10-2(14)71	Cores	100	98	-8	53	38	20	6.4
	Diff.	0	-8	-2	0	0	-2	+0.6
GROUP 9								
Klein - South	M.D.	100	90	75	53	37	18	6.0
F-HES 16-2(3)29	Cores	100	93	79	56	39	22	5.6
	Diff.	0	-3	-4	-3	-2	-4	+0.4
GROUP 10								
Miles City - NW.	M.D.	100	90	77	56	34	17	6.0
F-HES 18-1(2)1	Cores	100	90	76	56	38	21	4.1
	Diff.	0	0	+1	0	-4	-4	+1.9

BB:0:gg:10i



Predicted Wet Fatigue Performance Life
Years
0
5
10
15
20
25
30
35
40
1
2
3
4
5
6
7
8
9
10
Project
Mix Design–Lottman
Field Cores–Lottman


Predicted Wet Fatigue Performance Life
Years
0
5
10
15
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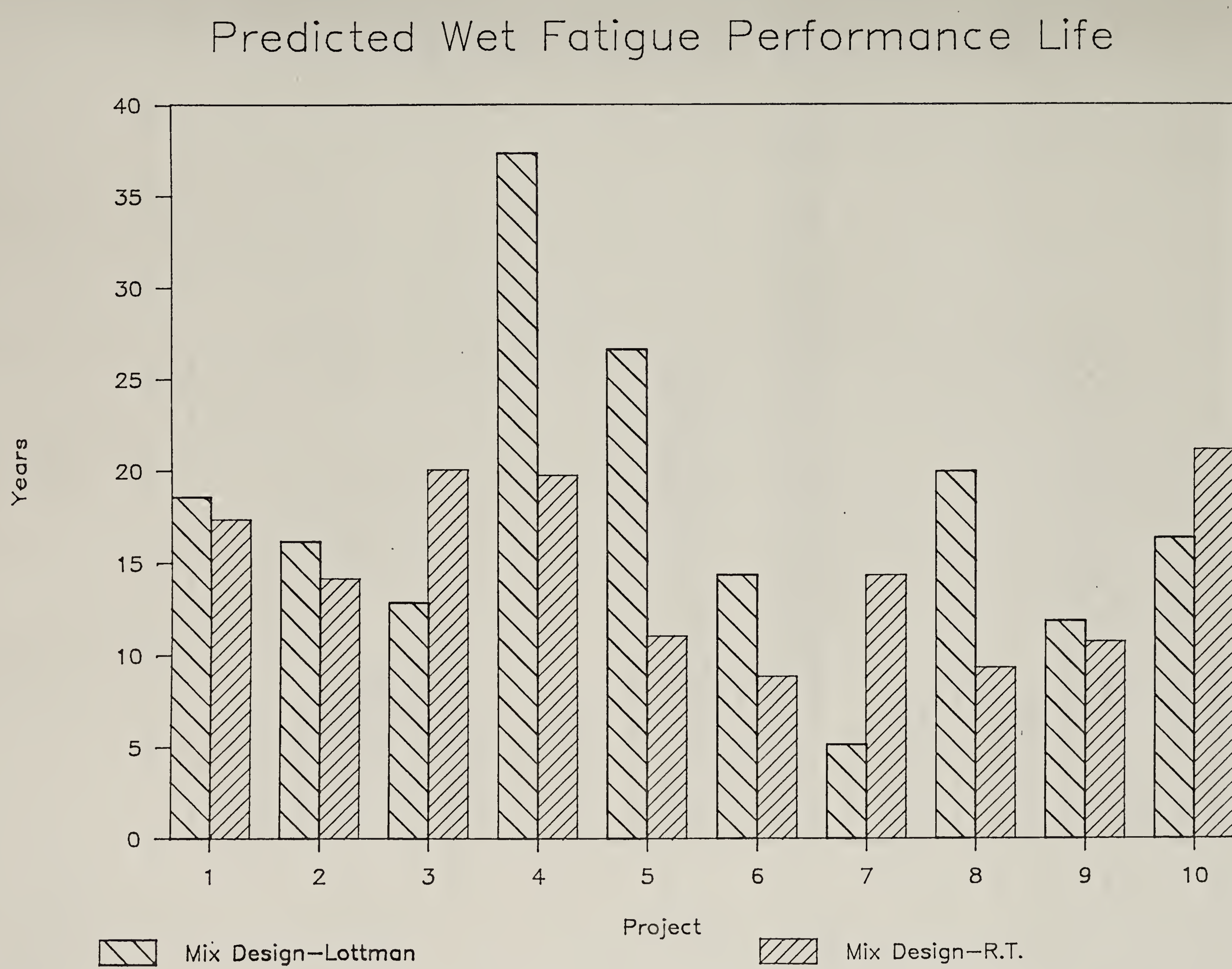
8
9
10
Project
Mix Design–R.T.
Field Cores–R.T.



Predicted Wet Fatigue Performance Life
Years
0
5
10
15
20
25
30
35
40
1
2
3
4
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6
7
8
9
10
Project
Mix Design—Lottman
Mix Design—R.T.


Predicted Wet Fatigue Performance Life
Years
0
5
10
15
20
25
30
35
40
1
2
3
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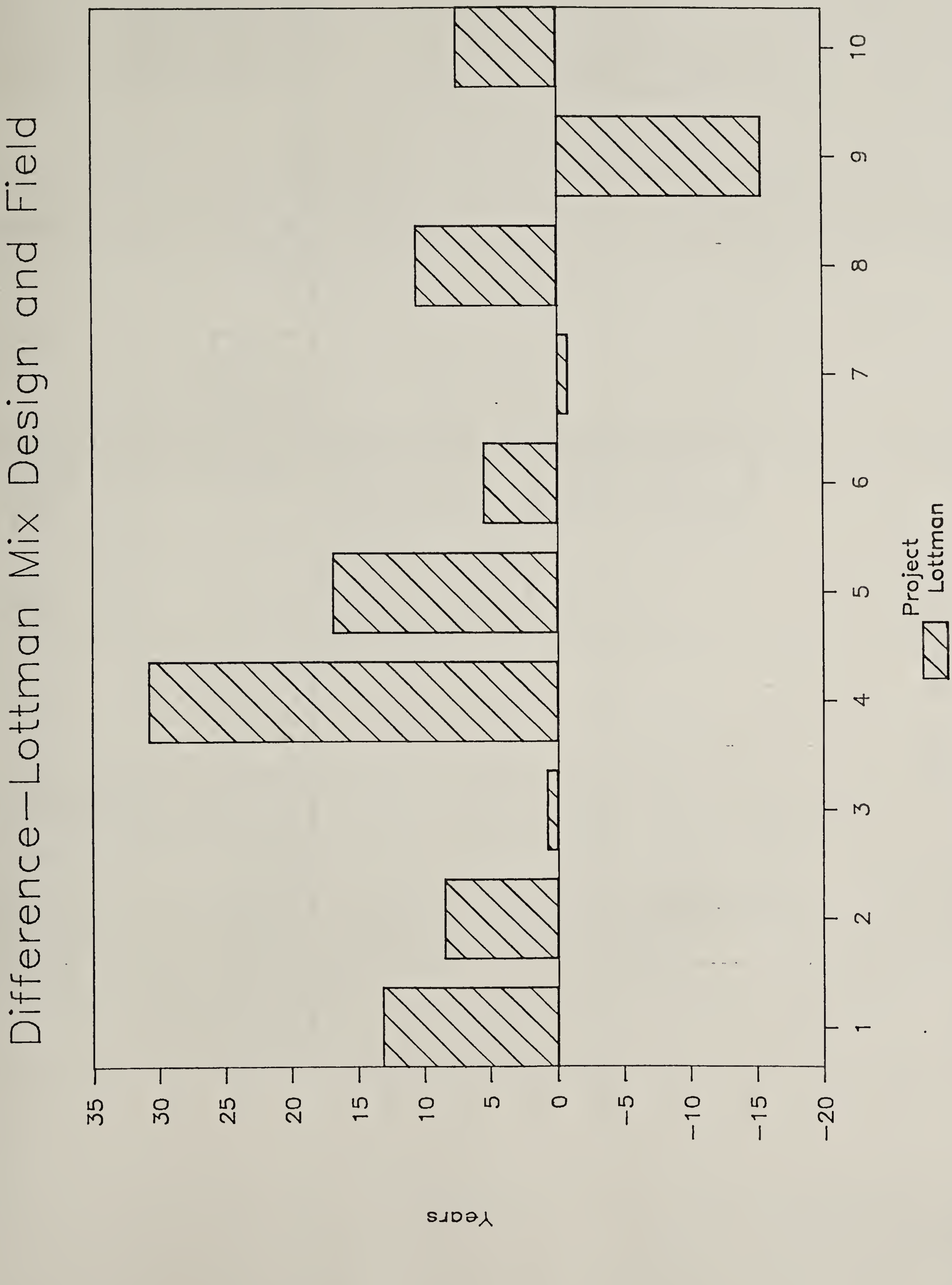
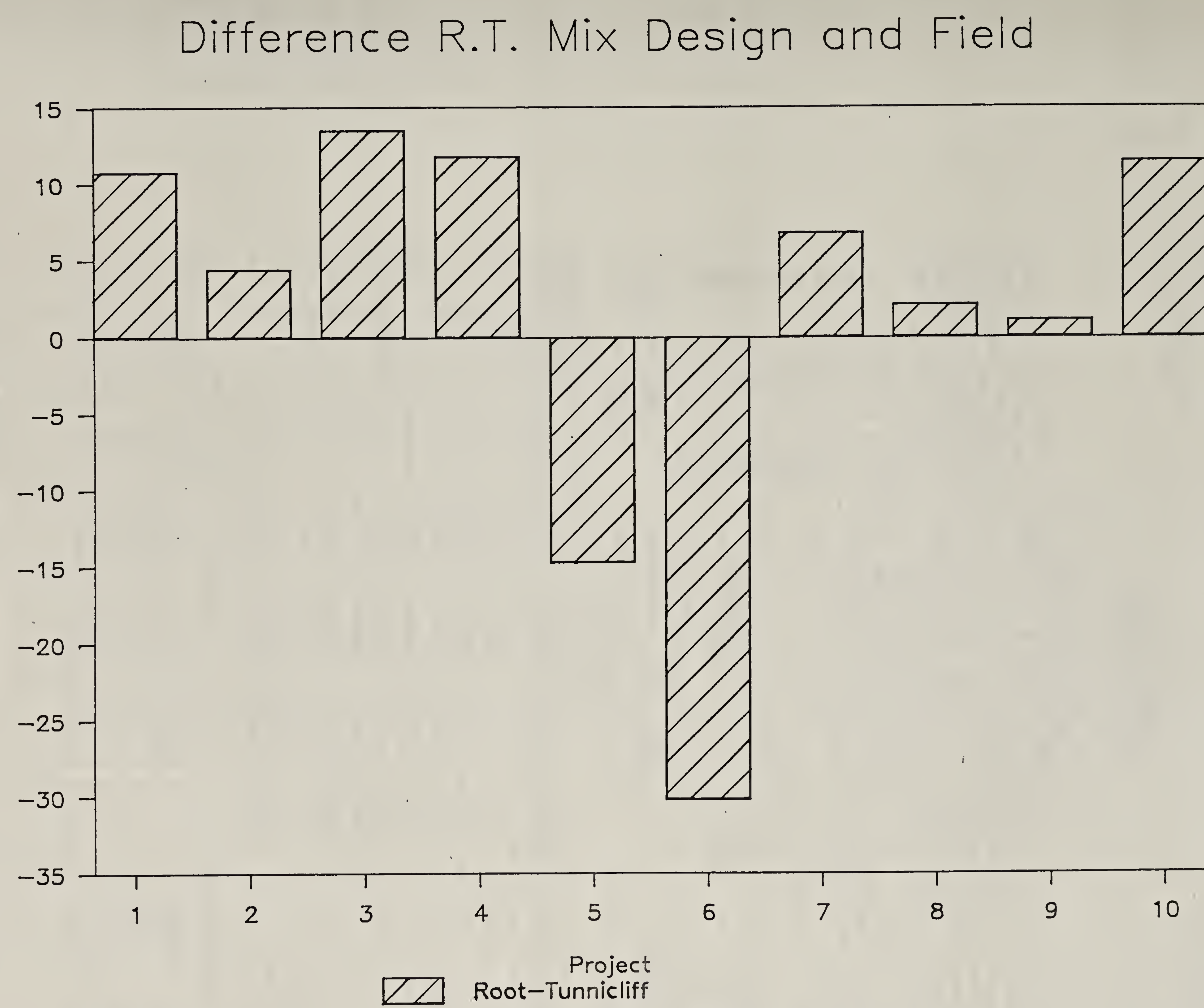
9
10
Project
Field Cores-Lottman
Field Cores-R.T.


Difference—Lottman Mix Design and Field
Years
35
30
25
20
15
10
5
0
−5
−10
−15
−20
1
2
3
4
5
6
7
8
9
10
Project
Lottman



Difference R.T. Mix Design and Field
Years
15
10
5
0
−5
−10
−15
−20
−25
−30
−35
1
2
3
4
5
6
7
8
9
10
Project
Root−Tunnicliff

Lab. Form No. 606
(Rev. 1/20/87)

0:214/MT-306/11

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE 3
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 614601 Sample No. 1 (10 sks) Project No. TRF 83-1(4)15
Termini Seeley Lake-Inez Lake
Date Sampled 9/2/87 Date Received 9/4/87
Sampled by Childers Title LS I Address Missoula
Submitted by Smola Title MLT II Address "
Area Source Represented by Lab. No. 611573-8 & 611837-9 Sample taken at
Owner John Cahoon Address Seeley Lake, Mont

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	89	89
3/8"	76	76
4M	56	56
10M	36	36
40M	15	16
80M		
200M	7.4	8.0

LL NP PL NP PI NP Dust Ratio ____ Fracture 80
Wear 28 % Degradation ____ Sand Equiv. 46
** Absorption Cs 2.12 % Fine 2.24 % Blend 2.19
Bulk Dry Sp. Gr. of Agg. Fine 2.528 Coarse 2.558

VOLUME SWELL RESULTS

No. Treat. HARD 1.5 %; 1.5% Hyd. Lime HARD 1.4 %; 1.5% Fly Ash HARD 2.1 %
1.5% Cement ____ %

1984 ADT 750
2007 ADT 1500
18K 114

Recommended: 5.9 % 85/100 A/C; – % NONE

TEST RESULTS ON TRIAL BITUMINOUS MIXES
Marshall Results

Refinery CONOCO

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.0	2.403	2.274	5.4	1850	10	NORMAL
		5.5	2.396	2.289	4.5	1782	10	
		5.9	2.390	2.306	3.5	1875	10	INTERPOLATE
		6.0	2.389	2.310	3.3	1898	10	NORMAL
1.5	HYD. LIME	5.0	2.403	2.270	5.5	2000	12	
		5.5	2.396	2.285	4.6	1950	11	
		6.0	2.389	2.314	3.1	2038	13	
1.5	FLY ASH	5.0	2.403	2.309	3.9	2091	12	
		5.5	2.396	2.314	3.4	1811	11	
		6.0	2.389	2.328	2.6	2128	14	

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	5.9	305.6	207.0	67.8 %
1.5%	FLY ASH	5.9	321.6	103.5	32.2 %
1.5%	HYD.LIME	5.4	346.2	239.6	69.3 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesio
--	NONE	80
1.5%	FLY ASH	80
1.5%	HYD.LIME	85

~~Admin. Maint. Div.~~
2 District Engineer Missoula
1 Dist. Mat. Supr. Missoula
Area Lab –
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 14.0
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has HIGH absorption.
REMARKS:

	DATE	NAME
CHECKED	9/11/87	MFL

Robert Rei[illegible]
Chief, Materials Bureau
Dated 9/11/87

Lab. Form No. 606
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STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 614107 Sample No. 1 Project No. RS 330-1(7)0
Termini Ulm-South (North Section)
Date Sampled Date Received 8/26/87
Sampled by Title Address
Submitted by J. Powell Title DMS Address Gt. Falls
Area Source Represented by Lab. No. 611964-76 Sample taken at
Owner Stanley Bros/Mont. Power Address Ulm/Butte, Mt.

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	92	90
3/8"	75	75
4M	50	53
10M	36	34
40M	20	18
80M		
200M	5.5	6.0

LL NP PL NP PI NP Dust Ratio ____ Fracture 78
Wear 20 % Degradation ____ Sand Equiv. 55
** Absorption Cs 1.54 % Fine 1.64 % Blend 1.59

Bulk Dry Sp. Gr. of Agg. Fine 2.626 Coarse 2.619

VOLUME SWELL RESULTS

2.8 %	2.0 %	2.9
No. Treat. HARD	1.5% Hyd. Lime HARD	1.5% Fly Ash HARD
%		
1.5% Cement	%	

1979 ADT 110
1999 ADT 180
18K 6.9

Recommended: 6.2 % AS/100 A/C; — % NONE

TEST RESULTS ON TRIAL BITUMINOUS MIXES Refinery EXXON
Marshall Results

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.5	2.449	2.318	5.3	1950	9	NORMAL
	|	6.0	2.431	2.330	4.2	1859	10	|
	|	6.2	2.424	2.341	3.4	1932	10	INTERPOLATE
	|	6.5	2.414	2.357	2.4	2041	11	SLIGHTLY RIC
1.5	HYD. LIME	5.0	2.467	2.328	5.6	1988	11	NORMAL
|	|	5.5	2.449	2.344	4.3	2003	12	|
|	|	6.0	2.431	2.363	2.8	2084	11	SLIGHTLY RICH
1.5	FLY ASH	5.5	2.449	2.358	3.7	2158	11	NORMAL
|	|	6.0	2.431	2.379	2.1	1989	13	|
|	|	6.5	2.414	2.364	2.1	2063	12	SLIGHTLY RIC

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.2	238.0	161.6	67.9 %
1.5%	FLY ASH	5.8	245.2	207.8	84.8 %
1.5%	HYD.LIME	5.8	271.4	228.4	84.2 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesic
--	NONE	80
1.5%	FLY ASH	85
1.5%	HYD.LIME	85

~~Admin. Maint. Div.~~
2 District Engineer Great Falls
1 Dist. Mat. Supr. Great Falls
Area Lab —
Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 16.0
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has MODERATE absorption.
REMARKS:
Discussed with John Maykuth by BJB

Chief, Materials Bureau
Dated 9/3/87

	DATE	NAME
CHECKED	9/2/87	MPL

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 617440 Sample No. Project No. RTF BRF 8-2(15)34
Termini Helena-West(West Section)
Date Sampled 11/30/87 Date Received 12/4/87
Sampled by Sprague/Alley Title MSII & LT Address Butte
Submitted by Yarnall Title DMS Address Butte
Area Source Represented by Lab. No. 613857-65 Sample taken at
Owner 3/4" PMS Gr B Mix Design Address -

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"		100
1/2"		90
3/8"		78
4M		55
10M		40
40M		16
80M		
200M		6.0

LL NP PL NP PI NP Dust Ratio Fracture 72 %
Wear 32 % Degradation Sand Equiv. 38
** Absorption Cs 1.45 % Fine 1.57 % Blend 1.51 %

Bulk Dry Sp. Gr. of Agg. Fine 2.588 Coarse 2.599

VOLUME SWELL RESULTS

No. Treat. 6.8 % FIRM; 1.5% Hyd. Lime 5.4 % FIRM; 1.5% Fly Ash 6.4 % FIRM %
1.5% Cement %

1986 ADT 3302
2006 ADT 6200
18K 266

Recommended: 6.3*% 85/100 A/C; 1.4 % HYD. LIME
% HL and % ASPHALT BASED ON TOTAL WEIGHT

TEST RESULTS ON TRIAL BITUMINOUS MIXES Refinery CONOCO
Marshall Results

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
–	NONE	6.0	2.418	2.312	4.3	2078	11	NORMAL
		6.5	2.398	2.302	4.0	1608	10	SLIGHTLY RICH
		7.0	2.378	2.308	3.0	1827	10	
1.5	HYD. LIME	5.5	2.437	2.286	6.2	1725	11	NORMAL
		6.0	2.418	2.312	4.3	2078	11	
		6.3	2.406	2.320	3.6	2159	12	INTERPOLATED
		6.5	2.398	2.326	3.0	2213	12	SLIGHTLY RICH
1.5	FLY ASH	6.0	2.418	2.310	4.4	1900	11	NORMAL
		6.5	2.398	2.331	2.8	1950	11	SLIGHTLY RICH
		7.0	2.378	2.339	1.7	2260	12	

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.75	230.8	158.4	68.6 %
1.5%	FLY ASH	6.3	251.5	164.7	65.5 %
1.5%	HYD.LIME	6.3	269.8	204.5	75.8 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesion
--	NONE	70 %
1.5%	FLY ASH	75 %
1.5%	HYD.LIME	80 %
		%
		%

* NOTE: % ASPHALT IS BASED ON TOTAL WEIGHT

~~Admin. Maintenance Div.~~
2 District Engineer BUTTE
1 Dist. Mat. Supr. BUTTE
Area Lab —
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.

** NOTE: VMA of this Mix Design 16.2 %
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has MODERATE absorption.
REMARKS:

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STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
____ PLANT MIX BASE, GRADE
____ ROAD MIX SURFACING, GRADE

Lab. No. 616530 Sample No. ____ Project No. F BRF HES 1-2(37) RTF BRF HES 1-2(

Termini Kila E&W & Marion West

Date Sampled 10/21/87 Date Received 10/22/87

Sampled by R. French Title ALMS Address Kalispell

Submitted by " Title " Address "

Area Source Represented by Lab. No. 580038-47 Sample taken at

Owner David Klehm Address Kalispell, Mont.

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	84	86
3/8"	66	75
4M	41	53
10M	31	36
40M	12	16
80M		
200M	6.8	8.0

LL NP PL NP PI NP Dust Ratio ____ Fracture 70

Wear 24 % Degradation ____ Sand Equiv. 46

** Absorption Cs 1.95 % Fine 1.45 % Blend 1.65

Bulk Dry Sp. Gr. of Agg. Fine 2.630 Coarse 2.59

VOLUME SWELL RESULTS

No. Treat. 3.2 % HARD; 1.5% Hyd. Lime 2.9 % HARD; 1.5% Fly Ash 3.7 FIRM

1.5% Cement ____ % ____

1990 ADT 1400
2010 ADT 2100
____ 18K 103

Recommended: 5.6 % 85/100 A/C; 1.5 % HYDRATED LIME

TEST RESULTS ON TRIAL BITUMINOUS MIXES
Marshall Results

Refinery MRC

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.0	2.455	2.374	3.3	2266	11	NORMAL
	|	5.5	2.441	2.398	1.8	2235	12	|
	|	6.0	2.427	2.399	1.2	2003	14	SLIGHTLY R
1.5	HYD. LIME	5.0	2.455	2.367	3.8	2392	11	NORMAL
|	|	5.5	2.441	2.372	2.8	2431	14	|
|	|	5.6	2.438	2.377	2.5	2397	14	INTERPOLAT
		6.0	2.427	2.395	1.3	2262	17	NORMAL
1.5	FLY ASH	5.0	2.455	2.387	2.8	2184	12	|
|	|	5.5	2.441	2.405	1.5	2093	12	|
		6.0	2.427	2.404	0.9	1703	16	|

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	5.0	291.3	172.7	59.3 %
1.5%	FLY ASH	5.2	264.2	196.6	74.4 %
1.5%	HYD.LIME	5.2	290.5	225.2	77.5 %
1.5%	HYD. LIME	5.6	337.4	265.8	78.8 %
--	NONE	5.25	297.6	151.2	50.8 %

ADHESION RESULTS

%	Adhesive Agent	Adhesi
--	NONE	75
1.5%	FLY ASH	80
1.5%	HYD.LIME	85

~~Admin. Maintenance Div.~~
2 District Engineer Missoula
1 Dist. Mat. Supr. Missoula
1 Area Lab Kalispell
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File
1 HILDE CONSTRUCTION CO

** NOTE: VMA of this Mix Design 13.8 %
Absorption: 0-1.2 low, 1.2-2.0 moderate,
2.0 and above high

This aggregate has MODERATE absorption.

REMARKS: Discussed with John Meykuth by B, at an earlier date.

	DATE	NAME
CHECKED	11/2/87	MFL

Robert T. Rask
Chief, Materials Burea
Dated 11-2-87

Lab. Form No. 606
(Rev. 1/20/87)

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STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE ____
ROAD MIX SURFACING, GRADE ____

Lab. No. 609836 Sample No. ____ Project No. RS 438-1(4)0
Termini Nashua-North
Date Sampled 6/4/87 Date Received [illegible] 11 1987
Sampled by Cahill Title DMS Address Glendive
Submitted by " Title " Address "
Area Source Represented by Lab. No. 593720-26 Sample taken at ____
Owner William Lauckner Address Nashua

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	92	92
3/8"	76	77
4M	50	52
10M	34	36
40M	23	21
80M		
200M	4.3	5.0

LL NP PL NP PI NP Dust Ratio ____ Fracture 86
Wear 16 % Degradation ____ Sand Equiv. 53
** Absorption Cs 0.81 % Fine 1.39 % Blend 1.03

Bulk Dry Sp. Gr. of Agg. Fine 2.592 Coarse 2.596

VOLUME SWELL RESULTS

No. Treat. 4.2 % FIRM; 1.5% Hyd. Lime 2.7 % HARD; 1.5% Fly Ash 3.6 FIRM
1.5% Cement ____ % ____

1988 ADT 220
2008 ADT 320
18K 5.8

Recommended: 6.1 % 120/150 A/C; ____ % NONE

TEST RESULTS ON TRIAL BITUMINOUS MIXES
Marshall Results

Refinery EXXON

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.5	2.431	2.316	4.7	1275	7	SLIGHTLY RICH
		6.0	2.416	2.327	3.7	1251	7	/
		6.5	2.401	2.342	2.5	1363	10	RICH
		6.1	2.413	2.330	3.4	1273	8	INTERPOLATE
1.5	HYD. LIME	5.0	2.446	2.323	5.0	1300	8	NORMAL
		5.5	2.431	2.341	3.7	1388	8	/
		6.0	2.416	2.356	2.5	1425	10	SLIGHTLY RICH
1.5	FLY ASH	5.0	2.446	2.314	5.4	1075	7	NORMAL
		5.5	2.431	2.340	3.7	1272	8	/
		6.0	2.416	2.346	2.9	1238	9	SLIGHTLY RICH

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.25	147.2	113.8	77.3 %
1.5%	FLY ASH	5.6	166.3	144.8	87.1 %
1.5%	HYD.LIME	5.6	195.8	165.5	84.5 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesi...
--	NONE	70
1.5%	FLY ASH	75
1.5%	HYD.LIME	80

2 District Engineer GLENDIVE
1 Dist. Mat. Supr. GLENDIVE
1 Area Lab WOLF POINT
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 15.3
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has LOW absorption.
REMARKS:
discussed w. th. John [illegible] 6-19-87

	DATE	NAME
CHECKED	6/19/87	MFL

[illegible]
Chief, Materials Bure...
Dated 6-19-87

Lab. Form No. 606
(Rev. 1/20/87)

0:214/MT-306/11

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 613076 Sample No. 2 Project No. F BRF 4-1(5)26
Termini Bridger-Cromberg
Date Sampled 7/31/87 Date Received 8/4/87
Sampled by Neumiller Title DMS Address Billings
Submitted by " Title " Address "
Area Source Represented by Lab. No. 606811-12 Sample taken at
Owner U.S.A.(Farmers Home Admin.) Address Red Lodge, Mont.

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	91	90
3/8"	77	77
4M	53	53
10M	39	39
40M	19	18
80M		
200M	4.6	6.0

LL NP PL NP PI NP Dust Ratio Fracture 24
Wear 80 % Degradation Sand Equiv. 59
** Absorption Cs 1.61 % Fine 1.30 % Blend 1.43

Bulk Dry Sp. Gr. of Agg. Fine 2.599 Coarse 2.641

VOLUME SWELL RESULTS

No. Treat.	3.0 % HARD;	1.5% Hyd. Lime 2.2 % HARD;	1.5% Fly Ash 2.5 HAR
1.5% Cement	%	%	

1987 ADT 2370
2007 ADT 3150
18K 260

Recommended: 5.7 % 85/100 A/C; 1.5 % HYDRATED LI

TEST RESULTS ON TRIAL BITUMINOUS MIXES
Marshall Results

Refinery CONOCO

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.5	2.469	2.357	4.5	1625	9	NORMAL
	|	6.0	2.451	2.363	3.6	1638	9	|
	|	6.5	2.433	2.366	2.8	1716	8	SLIGHTLY R
1.5	HYD. LIME	5.0	2.487	2.350	5.5	1924	9	NORMAL
|	|	5.5	2.469	2.372	3.9	1846	10	|
|	|	5.7	2.462	2.378	3.4	1960	10	INTERPOLA
|	|	6.0	2.451	2.388	2.6	2132	10	SLIGHTLY R
1.5	FLY ASH	5.0	2.487	2.346	5.7	1391	8	NORMAL
|	|	5.5	2.469	2.361	4.4	1354	9	|
|	|	6.0	2.451	2.379	2.9	1820	10	SLIGHTLY R

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.0	270.6	112.2	41.5 %
1.5%	FLY ASH	5.7	344.6	178.3	51.7 %
1.5%	HYD.LIME	5.7	320.7	205.3	64.0 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhes
--	NONE	70
1.5%	FLY ASH	75
1.5%	HYD.LIME	85

2 District Engineer Billings
1 Dist. Mat. Supr. Billings
Area Lab
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 13.9
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has MODERATE absorption.
REMARKS:
Discussed with John Maykuth by BJB

DATE	NAME
CHECKED 8/12/87	BJB

R.T.K.
Chief, Materials Bure
Dated 8/13/87

Lab. Form No. 606
(Rev. 1/20/87)

0:214/MT-306/11

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 614026 Sample No. 1 Project No. F HES 8-4(11)99
Termini Three Forks-North
Date Sampled 8/20/87 Date Received 8/24/87
Sampled by Yarnall-Deighton Title DMS/MLS II Address Butte/Bozeman
Submitted by Yarnall Title DMS Address Butte
Area Source Represented by Lab. No. 608074-84 Sample taken at
Owner Patricia Woods Estate Address Bozeman, Mont.

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	82	86
3/8"	70	75
4M	52	53
10M	37	37
40M	21	18
80M		
200M	6.6	6.5

LL NP PL NP PI NP Dust Ratio ____ Fracture 80
Wear 20 % Degradation ____ Sand Equiv. 54
** Absorption Cs 0.79 % Fine 1.16 % Blend 0.95

Bulk Dry Sp. Gr. of Agg. Fine 2.613 Coarse 2.636

VOLUME SWELL RESULTS

No. Treat. 3.3 % HARD; 1.5% Hyd. Lime 2.6 % HARD; 1.5% Fly Ash 3.2 HARD
1.5% Cement ____ %

1986 ADT 1700
2006 ADT 2900
18K 105

Recommended: 5.6 % 85/100 A/C; - %

TEST RESULTS ON TRIAL BITUMINOUS MIXES
Marshall Results

Refinery Exxon

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	None	5.0	2.473	2.346	5.1	2197	9	Normal
		5.5	2.451	2.360	3.7	1768	9	
		6.0	2.429	2.372	2.3	2048	10	
		5.6	2.446	2.363	3.4	1824	10	Interpolated
1.5	Hyd. Lime	5.0	2.473	2.353	4.9	2028	10	Normal
		5.5	2.451	2.381	2.9	1859	10	
		6.0	2.429	2.399	1.2	2015	12	
	Fly Ash	5.0	2.473	2.354	4.8	1963	9	
		5.5	2.451	2.371	3.3	1820	11	
		6.0	2.429	2.388	1.7	1963	11	

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	5.6	190.2	184.6	97.1 %
1.5%	FLY ASH	5.5	226.1	220.5	97.6 %
1.5%	HYD.LIME	5.4	274.6	259.5	94.6 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesi
--	NONE	75
1.5%	FLY ASH	80
1.5%	HYD.LIME	85

~~Adm. Maint. Div.~~
2 District Engineer Glendive
1 Dist. Mat. Supr. Glendive
Area Lab —
Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 14.8
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has LOW absorption.
REMARKS:
Discussed with John Meykuth by GJB

CHECKED DATE 9/28/87 NAME MFL

Chief, Materials Bureau
Dated

Lab. Form No. 606
(Rev. 1/20/87)

0:214/MT-306/11

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 614645 Sample No. Project No. RRS 10-2(14)71
Termini Big Sandy Railroad Overpass-Bypass
Date Sampled 09/03/87 Date Received 9/8/87
Sampled by J Brummer Title ALS II Address Havre
Submitted by J. Powell Title DMS Address Gt. Falls
Area Source Represented by Lab. No. 580286-97 Sample taken at
Owner George Schlack Address Big Sandy, Mont.

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	96	90
3/8"	78	78
4M	47	53
10M	35	38
40M	18	18
80M	9	
200M	6.1	7.0

LL NP PL NP PI NP Dust Ratio Fracture 81
Wear 27 % Degradation Sand Equiv. 36
** Absorption Cs 1.57 % Fine 1.84 % Blend 1.70

Bulk Dry Sp. Gr. of Agg. Fine 2.580 Coarse 2.585

VOLUME SWELL RESULTS

6.9 % 5.1 % 5.3
No. Treat. FIRM ; 1.5% Hyd. Lime FIRM ; 1.5% Fly Ash FIRM
%
1.5% Cement %

1984 ADT 1145
2004 ADT 1600
18K 46.7

Recommended: 5.75 % 85/100 A/C; 1.5 % HYDRATED LIME

TEST RESULTS ON TRIAL BITUMINOUS MIXES Refinery MRC
Marshall Results

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.5	2.434	2.302	5.4	1560	9	NORMAL
		6.0	2.416	2.323	3.8	1976	10	
		6.5	2.398	2.336	2.6	1937	10	SLIGHTLY RIC
1.5	HYD. LIME	5.0	2.452	2.320	5.4	1911	10	NORMAL
		5.5	2.434	2.326	4.4	2015	9	
		5.75	2.425	2.338	3.6	2028	10	INTERPOLATE
		6.0	2.416	2.350	2.7	2041	10	SLIGHTLY RIC
1.5	FLY ASH	5.0	2.452	2.323	5.3	1495	10	NORMAL
		5.5	2.434	2.325	4.5	1573	9	
		6.0	2.416	2.341	3.1	1703	9	

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.1	218.1	118.6	54.4 %
1.5%	FLY ASH	5.9	233.2	183.9	78.9 %
1.5%	HYD.LIME	5.75	269.8	224.5	83.3 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesio
--	NONE	75
1.5%	FLY ASH	80
1.5%	HYD.LIME	85

~~Admin. Mine. Div.~~
2 District Engineer GREAT FALLS
1 Dist. Mat. Supr. GREAT FALLS
1 Area Lab HAVRE
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 14.2 %
Absorption: 0-1.2 low, 1.2-2.0 moderate,
2.0 and above high

This aggregate has MODERATE absorption.
REMARKS:
Discussed with John Maykuth
by BJB

R.T.S.
Chief, Materials Burea
Dated 9/16/87

	DATE	NAME
CHECKED	9/16/87	MFL

Lab. Form No. 606
(Rev. 1/20/87)

0:214/MT-306/11

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4 PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE ____
ROAD MIX SURFACING, GRADE ____

Lab. No. 612789 Sample No. 2 Project No. F HES 16-2(3)29
Termini Klein-South
Date Sampled 7-27-87 Date Received 7-28-87
Sampled by K Neumiller Title DMS Address Billings
Submitted by " Title " Address "
Area Source Represented by Lab. No. 591479-591489 Sample taken at Stockpile
Owner Bill Michaels Address

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	90	90
3/8"	75	75
4M	51	53
10M	37	37
40M	21	18
80M		
200M	5.2	6.0

LL NP PL NP PI NP Dust Ratio ____ Fracture 83
Wear 19 % Degradation ____ Sand Equiv. 63
** Absorption Cs 1.10 % Fine 1.72 % Blend 1.36

Bulk Dry Sp. Gr. of Agg. Fine 2.592 Coarse 2.639

VOLUME SWELL RESULTS

No. Treat. 2.2 % HARD; 1.5% Hyd. Lime 1.6 % HARD; 1.5% Fly Ash 1.9 HARD
1.5% Cement ____ % ____ %

1986 ADT 1560
2006 ADT 2000
18K 110

Recommended: 5.6 % 85/100 A/C; 1.5 % HYDRATED LIME

TEST RESULTS ON TRIAL BITUMINOUS MIXES
Marshall Results

Refinery CENEX

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.5	2.454	2.337	4.8	1788	10	NORMAL
		6.0	2.432	2.347	3.5	1807	11	
		6.5	2.410	2.366	1.8	1872	11	SLIGHTLY RIC
1.5	HYD. LIME	5.5	2.454	2.360	3.8	1888	10	NORMAL
		5.6	2.450	2.363	3.6	1880	10	INTERPOLATE
		6.0	2.432	2.373	2.4	1846	11	NORMAL
		6.5	2.410	2.383	1.1	2132	13	SLIGHTLY RI
1.5	FLY ASH	5.5	2.454	2.336	5.7	1748	10	NORMAL
		6.0	2.432	2.362	3.7	1861	10	
		6.5	2.410	2.403	0.3	2366	10	SLIGHTLY RICH

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.0	246.7	159.2	64.5 %
1.5%	FLY ASH	5.6	335.8	211.7	63.0 %
1.5%	HYD.LIME	5.6	327.9	266.6	81.3 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesi
--	NONE	80
1.5%	FLY ASH	80
1.5%	HYD.LIME	85

2 District Engineer Billings
1 Dist. Mat. Supr. Billings
Area Lab ——
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sect.
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 14.4
Absorption: 0-1.2 low, 1.2-2.0 moderate, 2.0 and above high

This aggregate has MODERATE absorption.
REMARKS:
Discussed w/John Mykellki Bob Tholt
8-5-87

Chief, Materials Bure
Dated 8-5-87

CHECKED DATE 8/5/87 NAME MFL

Lab. Form No. 606
(Rev. 1/20/87)

STATE OF MONTANA
DEPARTMENT OF HIGHWAY
Material Bureau

3/4" PLANT MIX SURFACING, GRADE B
PLANT MIX BASE, GRADE
ROAD MIX SURFACING, GRADE

Lab. No. 607974 Sample No. 1 Project No. F HES 18-1(2)1
Termini Miles City-NW
Date Sampled 4/10/87 Date Received APR 14 1987
Sampled by Peaslee Title LT III Address Miles City
Submitted by Jackman Title LS II Address "
Area Source Represented by Lab. No. 606045-53 Sample taken at
Owner Eckart Construction Address Miles City, Mt.

TEST RESULTS ON AGGREGATE

	% Passing As Received	% Passing As Tested
1-½"		
1"		
3/4"	100	100
1/2"	90	90
3/8"	75	77
4M	55	56
10M	33	34
40M	16	17
80M		
200M	4.8	6.0

LL NP PL NP PI NP Dust Ratio ___ Fracture 89 %
Wear 18 % Degradation ___ Sand Equiv. 85
** Absorption Cs 1.54 % Fine 2.02 % Blend 1.78 %

Bulk Dry Sp. Gr. of Agg. Fine 2.543 Coarse 2.563

VOLUME SWELL RESULTS

2.5 % No. Treat. HARD ; 1.8 % 1.5% Hyd. Lime HARD ; 1.4 % 1.5% Fly Ash HARD %
% 1.5% Cement ___ %

1986 ADT 1091
2006 ADT 1700
18K 46.8

Recommended: 6.5 % AC-10 A/C; NO %

TEST RESULTS ON TRIAL BITUMINOUS MIXES Refinery Asphalt Supply
Marshall Results

Mineral Filler %	Mineral Filler Type	% Asphalt	Rice Gravity	Density (Gm/cc)	% Voids	Lb. Stability	Flow	Appearance
	NONE	5.5	2.410	2.276	5.6	1824	14	NORMAL
		6.0	2.395	2.293	4.3	1848	16	
		6.5	2.380	2.294	3.6	2002	17	
1.5	HYD. LIME	5.5	2.410	2.277	5.5	1680	17	
		6.0	2.395	2.284	4.6	1716	19	
		6.5	2.380	2.307	3.1	1908	18	
1.5	FLY ASH	6.0	2.395	2.309	3.6	1723	18	
		6.5	2.380	2.302	3.3	1512	16	
		7.0	2.365	2.327	1.6	1776	23	

IMMERSION COMPRESSION RESULTS

Mineral Filler %	Mineral Filler Type	Percent Asphalt	Dry Break psi	Wet Break psi	Retained Strength
--	NONE	6.5	284.1	251.5	88.5 %
1.5%	FLY ASH	6.4	298.4	248.3	83.2 %
1.5%	HYD.LIME	6.4	350.9	349.4	99.6 %
					%
					%

ADHESION RESULTS

%	Adhesive Agent	Adhesion
--	NONE	75 %
1.5%	FLY ASH	80 %
1.5%	HYD.LIME	85 %
		%
		%

2 District Engineer Glendive
1 Dist. Mat. Supr. Glendive
1 Area Lab Miles City
1 Chief Const. Bureau
1 Chief Materials Bureau
1 Surfacing Design Sec..
2 Bit. Mix Design Sect.
1 FHWA
1 Materials Bureau File

** NOTE: VMA of this Mix Design 15.6
Absorption: 0-1.2 low, 1.2-2.0 moderate,
2.0 and above high

This aggregate has MODERATE absorption.
REMARKS:
Discussed with John Mayfuth 5/5/87 BJB

R.F.G.
Chief, Materials Bureau
Dated 5/5/87

	DATE	NAME
CHECKED	4/21/87	MFE

METHODS OF SAMPLING AND TESTING

MT-204

METHOD OF TEST FOR
SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

(Modified AASHTO T 84-77)

Scope

1. (a) This method covers the determination of bulk and apparent specific gravity, 73.4/73.4 F (23/23 C) and absorption of fine aggregate. Bulk specific gravity is the characteristic generally used for calculations of aggregate displacement in portland cement concrete.

(b) This method determines (after 15 hours in water) the bulk specific gravity, the bulk specific gravity on the basis of weight of saturated surface-dry aggregate, the apparent specific gravity, and the absorption as defined in the Standard Definitions of Terms Relating to Specific Gravity, MT-206.

Apparatus

2. (a) *Balance* - A balance having a capacity of 1 kilogram or more and sensitive to 0.1 gram or less.

(b) *Flask* - A volumetric flask of 500 milliliters capacity, calibrated to 0.15 milliliters at 68 F (20 C).

(c) *Mold* - A metal mold in the form of a frustum of a cone 1.5 in. (38 mm) in diameter at the top, 3.5 in. (89 mm) in diameter at the bottom, and 2.9 in. (74 mm) in height, with the metal having a minimum thickness of 20 gage (approximately 0.9 mm).

(d) *Tamper* - A metal tamper weighing 12 ± ½ ounces (340 ± 15 grams) and having a flat circular tamping face 1 ± 1/8 in. (25 ± 3 mm) in diameter.

(e) *Thermometer* - An ASTM 17 F (or 17 C) thermometer having a range of 66 - 80 F. (19-27 C)

Calibration of Volumetric Flask

3. Determine the mass of the volumetric flask filled to its calibration capacity with water at 73.4 ± 3 F (23 ± 1.7 C) using the following formula:

$$B = 0.9976V + W$$

Where:

B = Mass of flask filled with water, gm.
V = Volume of flask, ml., and
W = Mass of flask, empty, gm.

Note 1 - Calibrate the volumetric flask to an accuracy of 0.15 ml. at 68 F (20 C).

Selection and Preparation of Sample

4. A test sample of approximately 1000 grams shall be obtained in accordance with MT-417. The test sample shall be dried in a suitable pan or container to constant mass at a temperature of 230 ± 9 F (110 ± 5 C). Allow it to cool to comfortable handling temperature, cover with water, and permit to stand for 15 to 19 hours. *(Note 2)* Spread the sample on a flat surface, exposed to a gently moving current of warm air, and stir frequently to secure uniform drying. Continue this operation until the test sample approaches a free-flowing condition. Then place a portion of the partially dried fine aggregate loosely into the mold, held firmly on a smooth non-absorbent surface with the large diameter down, lightly tamp the surface 25 times with the tamper, and lift the mold vertically. If moisture is still present, the fine aggregate will retain the molded shape. Continue drying with constant stirring and test at frequent intervals, until the tamped fine aggregate slumps slightly upon removal of the mold. This indicates that it has reached a surface-dry condition. *(Note 3)* If desired, mechanical aids may be employed to assist in achieving the saturated surface-dry condition.

Note 2 - Where the absorption and specific gravity values are to be used in proportioning concrete mixtures with aggregates used in their naturally moist condition, the requirement for drying to constant weight may be eliminated and, if the surfaces of the particles have been kept wet, the 15 hour soaking may also be eliminated. Values for absorption and for specific gravity in the saturated-surface-dry condition may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with paragraph 4.

Note 3 - The procedure described in Paragraph 4 (Selection and Preparation of Sample) is intended to ensure that the first trial determination will be made with some surface water in the sample. If the fine aggregate slumps on the first trial, it has been dried past the saturated and surface-dry condition. In this case thoroughly mix a few milliliters of water with the fine aggregate and permit the sample to stand in a covered container for 30 minutes. The process of drying and testing for the free-flowing condition shall then be resumed.

Procedure

5. (a) Immediately introduce into the flask 500.0 g. *(Note 4)* of the fine aggregate, prepared as described in paragraph 4, Selection and Preparation of Sample, and fill with water to approximately 90 percent of capacity. Roll, invert and agitate the flask to eliminate all air bubbles. Adjust its temperature to 73.4 ± 3 F (23 ± 1.7 C), if necessary, by immersion in circulating water and bring the water level in the flask to its calibrated capacity. Determine total mass of the flask, sample, and water. *(Note 5)* Record this and all other masses to the nearest 0.1 g.

Note 4 - An amount other than 500 g. but not less than 50 g. may be used provided that mass is inserted in place of the figure "500" wherever it appears in the formulas. If the mass used is less than 500 g. limits on accuracy of weighing and measuring must be scaled down in proportion.

Note 5 - As an alternative, the quantity of water necessary to fill the flask may be determined volumetrically using a buret accurate to 0.15 ml. The total mass of the flask, sample, and water is then computed as follows:

$$C = 0.9976\ V_a + 500 + W$$

where:

C = mass of flask filled with sample plus water, g.,
Va = volume of water added to flask, and
W = mass of the flask empty, g.

(b) The sample shall be dried to a condition of constant mass such that it will not lose more than 0.1 percent of moisture after 2 hours of drying at the specified temperature. Such a condition of dryness can be verified by weighing the sample before and after successive 2 hour drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at the specified temperature for a equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.

Note 6 - In lieu of weighing the sample which has been removed from the flask, a second 500 gram saturated surface dry sample may be used to determine the dry mass.

Bulk Specific Gravity

6. Calculate the bulk specific gravity 73.4/73.4 F (23/23 C), as defined in MT-206 as follows:

$$\text{Bulk sp. gr.} = \frac{A}{B + 500 - C}$$

Where:

A = mass of oven-dry sample in air, g.
B = mass of flask filled with water, g., and
C = mass of flask with sample and water to calibration mark, g.

Bulk Specific Gravity (Saturated Surface-Dry Basis)

7. Calculate the bulk specific gravity, 73.4/73.4 (23/23 C), on the basis of saturated surface-dry aggregate as follows:

$$\text{Bulk sp. gr. (Saturated surface-dry basis)} = \frac{500}{B + 500 - C}$$

Apparent Specific Gravity

8. Calculate the apparent specific gravity 73.4/73.4 F (23/23 C), as defined in MT-206 as follows:

$$\text{Apparent sp. gr.} = \frac{A}{B + A - C}$$

Absorption

9. Calculate the percentage of absorption, as defined in MT-206, as follows:

$$\text{Absorption, percent} = \frac{500 - A}{A} \times 100$$

Precision

10. Data from carefully conducted tests at one laboratory yielded the following for tests on the same sample. Different samples from the same source may vary more.

(a) For specific gravity, single-operator and multi-operator precision (2S limits) less than ± 0.02 from the average specific gravity. Differences greater than 0.03 between duplicate tests on the same sample by the same or different operators should occur by chance less than 5 percent of the time (D2S limit less than 0.03).

(b) For absorption, single-operator precision ± 0.31 from the average percent absorption 95 percent of the time (2S limits). Multi-operator tests are probably less precise. The difference between tests by the same operator on the same sample should not exceed 0.45 more than 5 percent of the time (D2S limit).

MT-205

METHOD OF TEST FOR SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATES

(Modified AASHTO T 85-77)

Scope

1. (a) This method covers the determination of bulk and apparent specific gravity, 73.4/73.4F (23/23C) and absorption of coarse aggregate. Bulk specific gravity is the characteristic generally used for calculations of aggregate displacement in portland cement concrete.

(b) This method determines (after 15 hours in water) the bulk specific gravity, the bulk specific gravity on the basis of weight of saturated surface-dry aggregate, the apparent specific gravity, and the absorption as defined in the Standard Definitions of Terms Relating to Specific Gravity, MT-206.

Apparatus

2. (a) Balance - A balance having a capacity of 5 kilograms or more and sensitive to 1.0 gram or less.

(b) *Sample Container* - basket of No. 6 (3.35 mm) or 8 (2.36mm) mesh and with sufficient capacity to handle the 5 kg. (5.75 liter [359 cu. in.]) minimum sample.

(c) *Suitable apparatus* for suspending the sample container in water from the center of the scale pan or balance.

(d) *Thermometer* - An ASTM 17 F (or 17 C) thermometer having a range of 66 - 80 F. (19 - 27 C)

Test Sample

3. An approximate 5 kilogram test sample shall be obtained in accordance with MT-417. Material passing the 4 mesh (4.75 mm) sieve shall be rejected.

Procedure

4. (a) After thoroughly washing to remove dust or other coatings from the surface of the particles, dry the sample to constant mass at a temperature of 230 ± 9F (110 ± 5C), cool in air at room temperature for 1 to 3 hours *(Note 1)* and then immerse in water at room temperature for a minimum time of 15 hours.

Note 1 - Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for drying to constant mass may be eliminated, and if the surfaces of the particles in the sample have been kept continuously wet until test, the 15 hour soaking may also be eliminated. Values for absorption and for specific gravity in the saturated-surface-dry

condition may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with paragraph 4(a).

(b) Remove the sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. Take care to avoid evaporation of water from aggregate pores during the operation of surface-drying. Weigh the sample in the saturated surface-dry condition. Record this and all subsequent weights to the nearest 1.0 gram.

(c) After weighing the saturated surface-dry sample, immediately place in the sample container and determine its mass in water at 73.4 ± 3F (23 ± 1.7C). Take care to remove all entrapped air before weighing by shaking the container while immersed. *(Note 2)*

(d) Dry the sample to constant mass at a temperature of 230 ± 9F (110 ± 5C), cool in air at room temperature 1 to 3 hours and weigh.

Note 2 - The container should be immersed to a depth sufficient to cover it and the test sample during weighing. Wire suspending the container should be the smallest practical size to minimize any possible effects of a variable immersed length.

Bulk Specific Gravity

5. Calculate the bulk specific gravity 73.4/73.4F (23/23C) as defined in the Standard Definitions of Terms Relating to Specific Gravity (MT-206) as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B - C}$$

where:

A = mass of oven-dry sample in air, gm.
B = mass of saturated surface-dry sample in air, gm. and
C = mass of saturated sample in water, gm.

Bulk Specific Gravity (Saturated Surface-Dry Basis)

6. Calculate the bulk specific gravity 73.4/73.4F (23/23C) on the basis of mass of saturated surface-dry aggregate as follows:

$$\text{Bulk Specific Gravity (Saturated Surface-Dry Basis)} = \frac{B}{B - C}$$

Apparent Specific Gravity

7. Calculate the apparent specific gravity 73.4/73.4F (23/23C) as defined in the Standard Definitions of Terms Relating to Specific Gravity (MT-206) as follows:

$$\text{Apparent Specific Gravity} = \frac{A}{A - C}$$

Absorption

8. Calculate the percentage of absorption as follows:

$$\text{Absorption, percent} = \frac{B - A}{A} \times 100$$

Precision

9. (a) Data from carefully conducted tests at one laboratory yielded the following for tests on the same sample. Different samples may vary more.

(b) For specific gravity, single-operator and multi-operator precision (2S limits) less than 0.01 from the average specific gravity. Differences greater than 0.01 between duplicate tests on the same sample by the same or different operators should occur by chance less than 5 percent of the time (D2S limit less than 0.01).

(c) For absorption, single-operator and multi-operator precision ± 0.09 from the average percent absorption 95 percent of the time (2S limits). The difference between single tests by the same or different operators on the same sample should not exceed 0.13 more than 5 percent of the time (D2S limit).

METHODS OF SAMPLING AND TESTING

MT-217

Method of Test for

DETERMINING PERCENTAGE OF CRUSHED PARTICLES

(Montana Test Method)

Scope

1. This test method describes a procedure for determining the percent by weight of crushed particles in the coarse portion (plus 4 mesh) of crushed aggregates.

Apparatus

2. (a) *Balance* - A balance or scale sensitive to 2.5 grams or .005 of a pound is required.

(b) *Sieves* - The sieves shall be of the woven wire type with square openings and shall conform to MT-405.

(c) *Splitter* - Any device may be used which will divide the sample into representative portions. However, the riffle-type splitter is preferable to hand-quartering.

(d) *Spatula* - A spatula or similar tool to aid in sorting aggregate particles.

Preparation of Sample

3. (a) Split the entire sample, as received from the field, to a size that will result in approximately 1/2 lb., or 250 grams, of the plus 4 mesh material. *(Table 1 indicates the approximate size the sample must be in order to yield approximately 1/2 pound of plus 4 mesh material)*

(b) After the sample is split to the desired size, sieve it over the 4 mesh sieve and discard the fraction passing the 4 mesh sie

(c) Do not attempt to adjust the plus 4 mesh portion of the sample to exactly 1/2 pound or 250 grams by adding or removing materi but weigh to the nearest 2.5 gram or .005 lb. and record the weight as *"Test Sample Weight"*.

Procedure

4. (a) Spread the sample on a clean flat surface large enough to permit the material to be spread thinly for inspection.

(b) Use the knife edge of a large spatula or similar tool to separate crushed particles from uncrushed particles. Any particle with one or more fractured face, regardless of size, shall be considered a crushed particle.

(c) When the separation is complete, weigh the crushed particles and record as, *"Weight of Crushed Particles"*.

Calculations

5. Calculate the percentage of crushed particles using the following formula:

$$\text{Percentage of Crushed Particles} = \frac{\text{Weight of Crushed Particles}}{\text{Test Sample Weight}} \times 100$$

Precautions

6. Wash and oven-dry dirty aggregates if the dirt or dust film obscures the surface, making it difficult to inspect particles for fractured faces.

Reporting of Results

7. Report the test results to the nearest whole percent on test report Form No. 123.

TABLE 1

% +4M in Sample	Split To	% +4M in Sample	Split To	% +4M in Sample	Split To	% +4M in Sample	Split To
100	.50 lb.	75	.67 lb.	50	1.00 lb.	25	2.00 lb.
95	.53 lb.	70	.71 lb.	45	1.11 lb.	20	2.50 lb.
90	.56 lb.	65	.77 lb.	40	1.25 lb.	15	3.34 lb.
85	.59 lb.	60	.83 lb.	35	1.43 lb.	10	5.00 lb.
80	.63 lb.	55	.91 lb.	30	1.67 lb.	5	10.00 lb.

METHODS OF SAMPLING AND TESTING

MT-227

METHOD OF TEST FOR DETERMINATION OF DEGRADATION VALUE (MONTANA METHOD)

1. Scope:
   1.1 This method covers procedures for determining the quality of fines produced by self-abrasion of aggregate in the presence of water.

   NOTE: This test cannot be used as an indicator of an aggregate's potential to produce fines during crushing handling and compaction.

2. Apparatus:
   2.1 Balance - 2000 g capacity, sensitive to 0.1 g

   2.2 Sieve Shaker - with 1 1/16 ± 1/8 in. throw on cam at 285±5 oscillations per min.

   2.3 Plastic Cannister - 7½ in. in diameter x 6 in. high.

   2.4 Sand Equivalent Cylinders

   2.5 Sand Equivalent Stock Solution

   2.6 Sieves - 10 mesh and 200 mesh

   2.7 Graduates - 500 ml tallform, 10 ml.

   2.8 Interval Timer

3. Samples:
   3.1 Pre-construction Proposed Surfacing samples for Degradation Value will be taken as prescribed in MT-201 (Note 1).

   NOTE 1
   Samples submitted from a rock quarry will consist of a representative portion of the coarse (+¼ in.) material only. In order to accurately evaluate the true characteristic of quarry rock for Degradation Value the fine material (-¼ in.) will be produced by mechanical crushing in the Materials Bureau.

4. Procedure:
   4.1 Crush the material to be tested to pass the 1/2 inch sieve.

   4.2 Grade enough material so that 500g of aggregate of each of the following can be obtained after washing and drying.

   (1) - 1/2 inch to + 1/4 inch
   (2) - 1/4 inch to +10 mesh

   4.3 Place material in wash pan and run fresh water over the material until the wash water is clear. See Note 2.

4.4 Gently deposit the material on a 10 mesh sieve and rinse until rinse water is clear. The material should not be agitated.

4.5 Gently transfer aggregate to a pan and oven dry each size to a constant weight of 500g. Oven temperature shall be 121°C (230°F ±9°F).

4.6 Place sample in the plastic cannister, add 200 cc of water, cover tightly and place in sieve shaker.

4.7 Agitate the material for 20 minutes.

4.8 Empty the cannister into nested No. 10 and No. 200 sieves placed in a funnel over a 500 ml graduate to catch all the water.

4.9 Wash out the cannister and continue to wash the aggregate with fresh water until the graduate is filled to the 500 ml mark. (The aggregate may drain 50-100 ml of water after washing has been stopped.)

4.10 Pour 7 ml of sand equivalent stock solution into a sand equivalent cylinder.

4.11 Bring all solids in the graduate into suspension by capping the graduate with the palm of the hand and turning it upside down and back as rapidly as possible about 10 times.

4.12 Immediately decant into the sand equivalent cylinder to the 15 in. mark and insert stopper in the cylinder.

4.13 Mix the contents of the cylinder by alternately turning the cylinder upside down and right side up, allowing the bubble to traverse from end to end. Repeat this cycle 20 times in approximately 35 seconds.

4.14 Place the cylinder on the table, remove stopper and start timer. After 20 minutes read and record the height of the sediment column to the nearest 0.1 in.

5. Calculations:

5.1 Calculate the Degradation Factor by the following formula:

$$D = \frac{(15-H)}{(15+1.75H)} \times 100$$

where:
D = Degradation Factor
H = Height of Sediment in Tube

B. Values may range from 0 to 100, with high values being the best materials. The formula places doubtful materials at about the mid-point of the scale, with poor ones below and good ones above that point. Table 1 shows Degradation Values (D) for various values of sediment height (H).

6. Reports:

6.1 All test results shall be reported on Lab Form 123.

TABLE NO. 1
DEGRADATION VALUE "D"

$$D = \frac{15-H}{15+1.75H} \times 100$$

H	D	H	D	H	D	H	D	H	D
0.0	100	3.1	58	6.1	35	9.1	19	12.1	8
0.1	98	3.2	57	6.2	34	9.2	19	12.2	8
0.2	96	3.3	56	6.3	33	9.3	18	12.3	7
0.3	95	3.4	55	6.4	33	9.4	18	12.4	7
0.4	93	3.5	54	6.5	32	9.5	17	12.5	7
0.5	91	3.6	54	6.6	32	9.6	17	12.6	6
0.6	90	3.7	53	6.7	31	9.7	17	12.7	6
0.7	88	3.8	52	6.8	30	9.8	16	12.8	6
0.8	87	3.9	51	6.9	30	9.9	16	12.9	6
0.9	85	4.0	50	7.0	29	10.0	15	13.0	5
1.1	82	4.1	49	7.1	29	10.1	15	13.1	5
1.2	81	4.2	48	7.2	28	10.2	15	13.2	5
1.3	79	4.3	48	7.3	28	10.3	14	13.3	4
1.4	78	4.4	47	7.4	27	10.4	14	13.4	4
1.5	77	4.5	46	7.5	27	10.5	13	13.5	4
1.6	75	4.6	45	7.6	26	10.6	13	13.6	4
1.7	74	4.7	44	7.7	26	10.7	13	13.7	3
1.8	73	4.8	44	7.8	25	10.8	12	13.8	3
1.9	71	4.9	43	7.9	25	10.9	12	13.9	3
2.0	70	5.0	42	8.0	24	11.0	12	14.0	3
2.1	69	5.1	41	8.1	24	11.1	11	14.1	2
2.2	68	5.2	41	8.2	23	11.2	11	14.2	2
2.3	67	5.3	40	8.3	23	11.3	11	14.3	2
2.4	66	5.4	39	8.4	22	11.4	10	14.4	1
2.5	65	5.5	39	8.5	22	11.5	10	14.5	1
2.6	63	5.6	38	8.6	21	11.6	10	14.6	1
2.7	62	5.7	37	8.7	21	11.7	9	14.7	1
2.8	61	5.8	37	8.8	20	11.8	9	14.8	0
2.9	60	5.9	36	8.9	20	11.9	9	14.9	0
3.0	59	6.0	35	9.0	20	12.0	8	15.0	0

METHODS OF SAMPLING AND TESTING

MT-305

METHOD OF TEST FOR VOLUME SWELL OF BITUMINOUS MIXTURES
(Montana Test Method)

1 Scope:

1.1 This test method provides for the determination of the maximum volume swell of compacted aggregates, soil, sand, or combination of mixtures passing the 10 Mesh (2.0 mm) sieve and stabilized with bituminous material.

2 Apparatus: The apparatus consists of the following:

2.1 Compaction Apparatus

2.1.1 Forming mold - This forming mold shall be a steel cylinder 2.50 inches (63.5 mm) or greater in outside diameter, 2.000 - 2.001 inches (50.80 - 50.8254 mm) inside diameter, and approximately 2.75 inches (69.85 mm) high. One end shall be recessed 0.245 - 0.250 inches (6.223 - 6.350 mm) with an inside diameter of 2.250 - 2.252 inches (57.1500 - 57.2008 mm) to fit the 2.247 - 2.249 inch (57.0738 - 57.1246 mm) base if the base plate method is used.

2.1.2 Plungers - Cylindrical steel plungers, fitted to the molding cylinders, 1.997 ± 0.001 inch (50.7238 ± 0.0254 mm) in diameter and 3 inches (76.2 mm) high.

2.1.3 Base - Solid steel, circular plate 1 inch (25.4 mm) thick and 3 inches (76.2 mm) in diameter, beveled and machined to a 2.247 - 2.249 inch (57.0738 - 57.1246 mm) top diameter above the mold seat.

2.2 Compression Testing Machine or Press - A compression machine or press capable of applying loads of 10,000 pounds (4535.9 kg.) or greater and indicating the applied load with a sensitivity of 50 pounds (22.7 kg.) or less.

2.3 Mixing Apparatus

2.3.1 Mixing pans shall be smooth and conform to the following dimensions:

a. Bottom inside diameter = approximately 4-3/4" (120.65 mm)
b. Top inside diameter = approximately 6-1/4 in. (158.75 mm)
c. Height = approximately 3 in. (76.2 mm)

2.3.2 Spatula approximately 7 in. (177.8 mm) long and 1/2 in. (12.7 mm) wide.

2 Appartatus: (continued)

2.3.3 Putty knife approximately 1-1/2 in. (38.1 mm) wide with a rounded tip.

2.3.4 Large metal scoop with handle.

2.3.5 Anti-slip, flexible rubber gloves

2.4 Heater - An electrical hot plate for warming pans of bituminous mix.

2.5 Vacuum Desiccator of convenient size with a vacuum gauge incorporated on the lid. The gauge shall be calibrated in inches or centimeters of Hg (mercury) vacuum.

2.6 Hand or motor driven vacuum pump with approximately two feet of plastic vacuum hose.

2.7 Stop-cock grease for desiccator seal.

2.8 Screw clamp.

2.9 Measuring and weighing apparatus.

2.9.1 A balance with a capacity of 500 grams and sensitive to 0.1 grams or less with a weighing scoop approximately 11 x 6 x 2-3/4 in. (279.4 x 152.4 x 69.85 mm), having a circular foot base, and equipped with a counter weight.

2.9.2 A measuring device that is accurately calibrated and equipped to determine heights and diameters of test specimens to the nearest 0.01 cm.

2.9.3 Mercury Displacement Cup - A glass or plastic cup with flat ground edge of convenient size to contain test specimens for mercury displacement measurement.

2.9.4 Glass dish approximately 10 x 6 x 2 in. (254 x 152.4 x 50.8 mm)

2.9.5 Porcelain pan approximately 15 x 10 x 2-1/2 in. (381 x 254 x 63.5 mm)

2.10 Drying Oven - A drying oven capable of maintaining a temperature of 140± 5°F (60 ± 3°C)

2.11 A 4 mesh (4.75 mm) and a 10 mesh (2.0 mm) sieve.

2.12 Thermometers, beakers, and a 100 ml, glass, graduated cylinder with intervals of 1.0 mm.

2.13 Pulverizing Apparatus - Either a mortar and rubber covered pestle or a mechanical device consisting of a power-driven rubber covered muller suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains.

3 Materials:

3.1 Distilled water with a pH of approximately 7. (Tap water is satisfactory if it does not interfere chemically with the test.)

3.2 Bituminous material - 200/300 Pen A.C.

3.3 Mercury.

4 Preparation of Aggregate:

4.1 A representative sample of the 10 mesh (2.00 mm) material as described in MT-200 (Dry Preparation of Aggregate) shall be prepared. The sample shall be large enough to produce approximately 400 grams of minus 10 mesh (2.00 mm) material at the conclusion of the pulverizing procedure.

5 Preparation of Bituminous Mix and Test Specimen:

5.1 Warm the 200/300 Pen Asphalt Cement for mixing to approximately 250± 15F (121± 8C).

5.2 Stabilize the hot plate at 425 to 475F (218 to 246C).

5.3 Stir the sample prepared in paragraph 4 with a spatula and transfer a 100 gram sample to the weighing scoop. Use the spatula to obtain a uniform discharge and to pull material from the bottom of the sample container when transferring the material. If desired, the material may be preheated in an oven 230± 9F (110± 5C).

5.4 Transfer the 100 gram sample from the weighing scoop to the mixing pan, stir with a putty knife and shake the material to one side of the mixing pan.

5.5 Place the mixing pan and sample on the balance and add 6.5 grams of 200/300 Pen A.C., do not pour asphalt on material; place the pan back on the hot plate.

5.6 When asphalt starts to flow into the sample, start mixing rapidly with a putty knife while shaking the mixing pan close to the hot plate. Avoid overheating the mix, as evidenced by smoking asphalt. Mix and shake until a thorough mixture is obtained. (See Note 1).

NOTE 1 – In the case of material having poor adhesion, the larger particles will only be slightly coated. Do not add more asphalt. Mix and shake until maximum coverage is obtained.

5.7 Pour the mixture from the mixing pan into a small scoop. Pour the mixture from the scoop into the assembled mold using the spatula to assist in obtaining a uniform discharge from the scoop. Insert the top plunger with a twist and a light tamp to seat firmly. Place the mold in the compression machine and at a uniform rate increase the load to a total of 6280 pounds in no less than 15 seconds. Maintain the maximum load for one minute and release. Remove the base plate with a twisting motion and mark the briquette in the mold with a wax crayon, applying light pressure.

5.8 After removing the base plate with a twisting motion and marking the briquette, turn the assembly upside down. Place the sleeve on top of the forming mold and using the jack apply pressure to the sleeve and top plunger. This will push the briquette and top plunger up into the sleeve.

5 Preparation of Bituminous Mix and Test Specimen: (continued)

(See Note 2). Cool and cure the briquette for three hours at room temperature.

NOTE 2 - If the briquettes tend to stick to the mold or plungers, preheat mold to 140F (60C).

5.9 Wipe the forming mold, base plate and plungers clean with a suitable solvent and dry with a cloth before forming each briquette.

5.10 Record the dimensions of the briquette at the end of the three hour cure. Dense briquettes are measured with either calipers or the mercury displacement method. (See Note 3).

NOTE 3 - Porous briquettes that may entrap mercury shall be measured with calipers only.

6 Twenty-Four Hour Volume Swell Procedure:

6.1 Prepare two briquettes in the manner described in paragraph 4 and paragraph 5.A.-J. One of the briquettes will be tested in accordance with paragraph 6 as a control and acceptance briquette and the other briquette will be tested as follows:

6.2 Check the vacuum equipment for leaks before any briquettes are put into the desiccator.

6.3 Fill the vacuum desiccator with distilled water and allow to stabilize at room temperature. Place the second briquette on the perforated tray in the vacuum desiccator and seal the top.

6.4 Subject the briquette to 8 inches (20.3 cm) of mercury vacuum for one hour. The 8 inches of vacuum will be applied within the desiccator in not less than one minute. The vacuum is maintained for one hour and released gradually to avoid pressure shock to the briquettes.

6.5 Keep the briquettes completely submerged in the distilled water at room temperature for an additional 23 hours. If necessary to transfer to another container of distilled water, wait 15 minutes after releasing pressure before effecting transfer.

6.6 Remove the briquette, blot the excess water and weigh. (See Note 3). In no event will the briquette be allowed to set for more than ten minutes before weighing is completed. The sides of the briquettes will be squeezed for recording condition of the briquette such as hard, firm, soft, soft and cracked, or disintegrated. Refer to paragraph 7 (calculations) to determine the percent of volume swell. (See Notes 4 & 5)

NOTE 4 - The test specimen shall be measured immediately after excess water is blotted off the specimen. If the specimen is allowed to set for any amount of time, the specimen will dry out and shrink giving erroneous swell results.

6 Twenty-Four Hour Volume Swell Procedure: (continued)

NOTE 5 - Mercury (Hg) is a poison and can be absorbed through the respiratory tract, the intestinal tract or through unbroken skin. Mercury is a cumulative poison and is a very volatile element. Dangerous levels are readily attained in air at 77 F (25 C). Tests involving the use of mercury should be performed under conditions of adequate ventilation. A fume hood is recommended for large numbers of samples or where the test is to be carried out frequently over extended periods of time. Protective gloves should be worn under conditions where skin contact with mercury may occur.

7 Calculation:

7.1 The volume swell, expressed as a percentage can be calculated by either of the two following methods.

7.1.1 Weight of Mercury

$$S = \frac{W_2 - W_3}{W_1 - W_2} \times 100$$

where:

S = volume swell, percent,
W_1 = weight of cup filled with mercury,
W_2 = weight of mercury and cup minus mercury lost because of immersion of cured briquette, and
W_3 = weight of mercury and cup minus mercury lost because of immersion of swollen briquette.

7.1.2 Volume of Specimen by Calipers

(1) $V = \pi r^2 h$

where:

V = volume of specimen
π = 3.14
r = radius of specimen
h = height of specimen

(2) $$S = \frac{V_2 - V_1}{V_1} \times 100$$

where:

S = volume swell, percent,
V_1 = volume of specimen before immersion, by caliper
V_2 = volume of specimen after immersion.

8 Report:

8.1 The report shall consist of the following:

Percent of Volume Swell,

Condition of specimen,

METHODS OF SAMPLING AND TESTING

MT-309

METHOD OF DETERMINING THE PERCENT OF ADHESION OF BITUMINOUS MATERIALS TO AGGREGATE

(Montana Method)

Scope:

1. This test is intended to evaluate the resistance of a bituminized mixture to its bituminous film removal by water.

Apparatus:

2. The apparatus required to perform the test is as follows:

A. Drying oven capable of maintaining a temperature of 248 F (120 C).
B. Electric hot plate
C. Various mixing pans
D. Putty knife
E. Balance with a capacity of 500 grams
F. ¼" wire screen
G. ½ gal. can
H. Water
I. "Red Devil" or equal paint shaker

Preparation of Sample:

3. The proposed aggregate is mixed with bituminous materials which may be (a) Asphalt Cement or Liquid Asphalt, or (b) Emulsified Asphalt. The preparation of the sample, depending upon the type of bituminous materials, is as follows:

A. Asphalt Cement or Liquid Asphalt

(1) Approximately 150 grams of plus ¼" aggregate and a sufficient quantity of the appropriate bituminous material are heated in separate containers in an oven at 248 F (120 C).

(2) After heating, the aggregate is mixed on a hot plate with just enough bituminous material to thoroughly coat the aggregate surfaces. A metal pan and putty knife are used to accomplish the mixing. The mixture is oven cured at 248 F (120 C) for one hour, then stirred and left to cool at room temperature.

B. Emulsified Asphalt

(1) The test procedure varies somewhat at the preliminary stage when an emulsified asphalt is used. Add a sufficient quantity of the appropriate emulsion to approximately 150 grams of dry, cool, plus ¼" aggregate and stir until the sample is completely covered. Excess emulsion is drained off on an elevated 4 Mesh wire screen. The mixture is oven cured at 113 to 122 F (45 to 50 C) for a period of 24 hours.

Procedure:

4. A. After the aggregate-bituminous mixture has cooled or cured for the prescribed time, it is removed from the mixing pan or draining screen with a putty knife.

Note: In order to facilitate removal, the mixture may be removed from the mixing pan or draining screen after the receptacle has been heated on a hot plate for approximately three seconds.

B. The mixture is then immersed in a half gallon can containing one quart of water at 49 to 73 F (15 to 25 C) for twenty-four hours.

C. At the end of the soaking period, the mixture is shaken in a "Red Devil" or other approved paint shaker for five minutes, after which it is carefully washed to remove any loose bituminous material, and placed on a doubled layer of paper toweling. The sample is spread evenly over an area approximately five inches in diameter so that the paper is not visible through the sample.

Evaluation:

5. Evaluation of adhesion is made only after the aggregate is thoroughly dry. A visual estimate of the proportion of the surfaces remaining coated with bituminous material is made and the results expressed as percent adhesion.

METHODS OF SAMPLING AND TESTING

MT-323

METHOD OF TEST FOR FABRICATING SPECIMENS FOR COMPRESSIVE STRENGTH OF BITUMINOUS MIXTURES

(Modified AASHTO T 167)

Scope:

1. This method of fabrication for compacted bituminous mixtures of the hot-mixed, hot-laid type, for use in pavement surfaces and base courses, is intended to provide test specimens for measuring the loss of cohesion resulting from the action of water (MT-324) and the compressive strength of these paving mixtures.

Apparatus:

2. A. Mold - The molds used for specimen fabrication consist of three principal parts: a heavy steel walled molding cylinder, a steel top plunger and a bottom plunger. The molding cylinder is machined and hardened with an inside diameter of 4 inches (100 mm) with a tolerance of +.005 inch (+.125/-.000 mm) and approximately 7 inches (175 mm) in length. The top and bottom molding plungers will fit inside the molding cylinders tightly enough to uniformly compress the asphalt mixture. The plungers are designed not to jam within the molding cylinder. Vertical alignment is maintained by steel webbing connecting the top and bottom of each plunger. The top plunger is approximately 6.5 inches (162 mm) in length with a diameter of 3.996 inches and a tolerance of +.000/-.005 inches, and the bottom plunger will be approximately 2.0 inches (50 mm) in length with a diameter of 3.996 inches with a tolerance of +.000/-.005 inches.

Note 1: *The lengths of the molding cylinder and plungers are not critical. When the molding cylinder is over the lower plunger and is resting on the temporary supports, the molding chamber created must be at least 6 inches (150 mm) in depth to accommodate an uncompacted sample and have room to start the top piston. The cylinder must not be more than two inches longer than the combined length of the upper and lower plunger to insure unrestricted compression of the asphalt specimen.*

B. Supports - Temporary supports will be provided to raise the molding cylinder enough to initiate double plunger action.

Note 2: *The mold, plungers and supports are used as accessories to a compressive press with a minimum capacity of 38,000 lbs.*

C. Oven - The convection oven for the preparation of hot mixtures shall be capable of being set to maintain any desired temperature from room temperature to 325°F (163°C).

D. Heating Device - A small hot plate with a continuously variable heating rate, a sand bath, an infrared lamp or an oven shall be provided for supplying sufficient heat under the mixing bowl to maintain the aggregate and bituminous material at the desired temperature during mixing.

E. Air Bath - The air bath shall be capable of either manual or automatic control for storing the specimens at 77 ± 1 F (25 ± 0.5 C) immediately prior to making the compression test.

F. Mixing Machine - The mixture should preferably be prepared in a mechanical mixer. Any type of mixer may be used provided it can be maintained at the required mixing temperature and will produce a well-coated, homogeneous mixture of the required size in 2 min. or less, and further provided that it is of such design that fouling of the blades will be minimized and each individual batch can be retrieved in essentially its entirety including asphalt and fines. Hand mixing may be used, if necessary, but for hot mixtures the time required to obtain satisfactory coating is often excessive and generally the test results are less uniform than when machine mixing is employed.

G. Spatulas - Limber for scraping the mixing bowl, and stiff, for spading the specimen in the mold, shall be provided.

H. Balance - A balance having a capacity of 5 kilograms or more and be sensitive to 0.1 gram or less.

Preparation of Test Mixtures:

3. A. The size of the individual batches shall be limited to the amount required for one test specimen. The percentage of asphalt cement can also be the optimum asphalt content as determined by Marshall Method for Field Control of Hot Mix Asphalt Paving (MT-311).

B. An initial batch shall be mixed for the purpose of "buttering" the mixture bowl and stirrers. This batch shall be emptied after mixing and the sides of the bowl and stirrers shall be cleaned of mixture residue by scraping with a small limber spatula but shall not be wiped with cloth or washed clean with solvent, except when a change is to be made in the binder or at the end of a run.

C. In preparing aggregates for making mixtures, a sieve analysis shall be made on each aggregate involved. All coarse and fine aggregates shall be separated individually and recombined in the necessary quantities to meet the formula under study. The weighed aggregate fractions for each batch shall be thoroughly mixed dry and then heated to the planned mix temperature in a convection oven before the bituminous material is added. A sufficient quantity of bituminous material for each batch shall be heated in a convection oven to the same temperature as the dry aggregates. Any residual bituminous material that is left over at the end of the day must be discarded.

D. When the bituminous material and dry aggregates have been brought to the mix temperature, the mixing bowl, which shall have been preheated to approximately the temperature of the aggregate, shall be charged with the preheated and dry mixed aggregate, the preheated bituminous material shall be weighed into the aggregate, and wet mixing shall be started and continued for not less than 90 s nor more than 120 s. Excessive loss of heat during mixing may be offset by the use of a small hot plate, sand bath, or infrared lamp under the mixing bowl, or a heating mantle may be used. The mixing bowl shall not be in direct contact with a hot plate, if used.

Molding and Curing Test Specimens:

4. Generally, the test specimens shall be cylinders with the same diameter tolerance as the molding cylinder and 4.0 ± 0.1 inches (100 mm ± 2.5 mm) in height. It is recognized that the size of the test specimens has an influence on the results of the compressive strength tests.

   A. Laboratory prepared mixtures shall be fabricated as quickly as possible after mixing as follows:

   B. Mixtures from a field project shall be brought to molding temperature by careful, uniform heating immediately prior to molding. The approximate mixing temperature for a particular asphalt will produce a viscosity of 170±20 Cst obtained by using the temperature-viscosity charts in MT 308. The approximate compaction temperature for a particular asphalt will produce a viscosity of 280±30 Cst obtained by using the temperature-viscosity charts in MT 308.

   C. Mix the measured weights of asphalt cement and dry aggregate (90-120S) at the determined mix temperature.

   D. While mixing is taking place, take the preheated mold and plungers (heated to the same temperature as the dry aggregate) and wipe them lightly with an oiled cloth to prevent sticking. Place the bottom plunger on the table of the press. Position the temporary supports on each side of the plunger and place the mold cylinder on them.

   E. Pour the bituminous mixture from the mixing bowl into a large scoop. Scrape the mixing bowl with a spatula, do not clean with solvent.

   F. Pour one half of the mixture from the scoop into the molding cylinder, using a spatula to obtain an even discharge. Spade vigorously twenty-five times with a heated spatula. Fifteen of the blows will be delivered around the inside of the mold, to reduce honeycombing, and the remaining ten at random over the mixture. The remaining half of the mixture shall then be quickly transferred to the molding cylinder and a similar spading action repeated. The spatula should penetrate the mixture as deeply as possible. A spatula having a slightly curved cross-section has been used to advantage by some laboratories.

   G. Round or cone-shape the top of the mixture to aid in firm seating of the upper plunger. Then place the upper plunger on the spaded mixture and slide the whole assembly under the press plates.

   H. The mixture, with the temporary supports in place, shall be compressed between the top and bottom plungers to an initial load of about 150 psi to set the mixture against the sides of the mold. The load shall then be released and the support bars removed to permit full double-plunger action.

   I. Smoothly and rapidly apply a load of approximately 3000 psi, maintain for 120S and release.

J. The specimen shall then be removed from the mold with an ejection device that provides a smooth, uniform rate of travel.

K. After removal from the mold, specimens shall be oven cured 15-24 hours at 140 ± 1°F (60 ± 0.5°C). In case specimens are to be stored dry for more than 24 h from completion of oven curing to compression testing, they shall be protected from exposure to the air by sealing them in closely fitting, airtight containers.

METHODS OF SAMPLING AND TESTING

MT-324

METHOD OF TEST FOR EFFECT OF WATER ON COHESION OF COMPACTED BITUMINOUS MIXTURES

(Modified AASHTO T 165)

1 Scope:

1.1 This method covers measurement of the loss of cohesion resulting from the action of water on compacted bituminous mixtures containing penetration grade asphalts. A numerical index of reduced cohesion is obtained by comparing the compressive strength of freshly molded and cured specimens with the compressive strength of duplicate specimens that have been immersed in water under prescribed conditions.

2 Apparatus:

2.1 High Temperature Water Bath - One or more automatically controlled water baths shall be provided for immersing the specimens. The baths shall be of sufficient size to permit total immersion of the test specimens. They shall be so designed and equipped as to permit accurate and uniform control of the immersion temperature of 140 ± 2 F (60 ± 1C). They shall be constructed of or lined with copper, stainless steel, or other nonreactive material. The water used for the wet storage of the specimens shall be either distilled or otherwise treated to eliminate electrolytes and the bath shall be emptied, cleaned, and refilled with fresh water for each series of tests. Tap water can be used for wet storage if it can be shown that it does not affect the test results of the immersed specimens.

2.2 Low Temperature Water Bath - A manually or automatically controlled water bath also shall be provided for bringing the immersed specimens to the temperature of 77 ± 2 F (25 ± 1 C) for the compression test. Any convenient pan or tank may be used provided it is of sufficient size to permit total immersion of the specimens.

2.3 Balance - A balance and a water bath with suitable accessory equipment will be required for weighing the test specimens in air and in water in order to determine their densities, the amount of absorption, and any changes in specimen volume resulting from the immersion test. The balance will have a capacity of 5 kilograms or more and be sensitive to 0.1 grams or less.

2.4 Flat plate - For very fragile specimens a supply of flat transfer plates of glass or metal will be required. One of these plates shall be kept under each of the specimens during the immersion period and during subsequent handling, except when weighing and testing, in order to prevent breakage or distortion of the specimens.

2 Apparatus: (continued)

2.5 Testing machine - The testing machine may be of any type of sufficient capacity that will provide a range of accurately controllable rates of vertical deformation. The rate of vertical deformation for the compression test is specified as 0.05 in. (1.3 mm) per min. per 1 in. (25 mm) of height of specimen. A controllable rate of 0.2 in. (5.1 mm) per minute is required for a 4 in. (200 mm) nominal height specimen. For central control laboratory installations the testing machine shall conform to the requirements of Methods of Verification of Testing Machines (AASHTO T 67). The testing machine shall be equipped with two steel bearing blocks with hardened faces, one of which is spherically seated and the other plane. The spherically seated block shall be mounted to bear on the upper surface of the test specimen and the plane block shall rest on the platen of the testing machine to form a seat for the specimen. The bearing faces of the plates shall have a diameter slightly greater than that of the largest specimens to be tested. The bearing faces, when new, shall not depart from a true plane by more than 0.0005 in. (0.013 mm) at any point and shall be maintained within a permissible variation limit of 0.001 in. (0.025 mm). In the spherically seated block, the center of the sphere shall coincide with the center of the bearing face. The movable portion of this block shall be held closely in the spherical seat but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

3 Test Sample:

3.1 At least four 4 x 4 inch (100 x 100 mm) cylindrical specimens (nominal dimension) shall be made for each test. The procedure described in Fabricating Specimens for Compressive Strength of Bituminous Mixture, MT-323, shall be followed in preparing the loose mixtures and in molding and curing the test specimens.

4 Procedure:

4.1 Allow each set of test specimens to cool for at least two hours after removal from the curing oven described in MT-323. Determine the Bulk Specific Gravity of random specimen from Group 2 in accordance with the procedures and calculation for Bulk Specific Gravity of Compacted Bituminous Mixture in section 5(a).

4.2 Sort each set of four specimens into two groups of specimens. Prepare the specimens in group 1 as described in 4.(b)1 and prepare the specimens in group 2 as described in 4.(b)2.

4.2.1 Group 1 - Bring the test specimens to the test temperature, 77 ± 2 F (25 ± 1 C), by storing them in an air bath maintained at the test temperature for not less than 4 hours then determine their compressive strengths.

4 Procedure: (continued)

4.2.2 Group 2 - Immerse the test specimens in water for 24 hr. at 140 ± 2 F (60 ± 1 C). Transfer them to a second water bath maintained at 77 ± 2 F (25 ± 1 C) for 2 hr. and then immediately determine their compressive strengths.

4.3 To determine the compressive strength of the specimens place the specimens in axial compression without lateral support loading the specimens at a rate of 0.2 inches (5.1 mm) per minute. The specimen is loaded at the above rate until failure occurs. The point of failure is defined as the maximum load obtained.

5 Calculation:

5.1 Calculate the bulk specific gravity of a random test specimen from Group 2 as follows:

$$\text{Bulk specific gravity} = \frac{A}{B-C}$$

where:

A = mass of oven-dry specimen in air, g.
B = mass of surface-dry specimen in air, g.
C = mass of specimen in water, g.

5.2 Calculate the maximum compressive strength of each specimen in pounds per square inch (psi) for a 4 inch (100 mm) diameter specimen as follows:

$$\text{Maximum compressive strength, psi} = \frac{A}{B}$$

A = the maximum load obtained for specimen in pounds.
B = area of surface loaded in inches squared. For a 4 inch (100 mm) nominal diameter specimen, it is 12.5664 inches squared.

5.3 Calculate the numerical index of resistance of bituminous mixtures to the detrimental effect of water as the percentage of the original strength that is retained after the immersion period. It shall be calculated as follows:

$$\text{Index of retained strength, \%} = \frac{S_2 \times 100}{S_1}$$

where:

S_1 = average compressive strength of dry specimens (group 1), and
S_2 = average compressive strength of immersed specimens (group 2).

6 Report:

6.1 The report shall include a random bulk specific gravity, the maximum compressive strengths for each specimen, and the percent of retained compressive strength as calculated in 5.(c). The report will also include the penetration range of the asphalt cement, the refinery where the asphalt was made, the percent of asphalt used and the mixing temperature of the test specimens.

7 Precision:

7.1 Single-Operator Precision - The single-operator standard deviation has been found to be 6 percent (see Note 1). Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 18 percent (see Note 1).

Note 1: These numbers represent, respectively the (1S) and D2S) limits as described in AASHTO Recommended Practice R4, for preparing Precision Statements for Test Methods for Construction Materials.

7.2 Multilaboratory Precision - The multilaboratory standard deviation has been found to be 18 percent (see Note 1). Therefore, results of two properly conducted tests from two different laboratories on identical samples of the same material should not differ by more than 50 percent (see Note 1).

APPENDIX A: Moisture Damage Procedures

This appendix presents the NCHRP 246[2] and NCHRP 274[3] procedures.

NCHRP 246

PREDICTIVE MOISTURE DAMAGE TEST METHOD USED IN NCHRP PROJECT 4-8(3)

EFFECT OF WATER-RELATED CONDITIONING ON INDIRECT TENSILE PROPERTIES OF COMPACTED BITUMINOUS MIXTURES

1. Scope

1.1 This method covers measurement of the change of diametral tensile strength and diametral (tensile) resilient modulus resulting from the effects of saturation and accelerated water conditioning of compacted bituminous mixtures. Internal water pressures in the mixtures are produced by vacuum saturation followed by a freeze and warm-water soaking cycle. Numerical indices of retained indirect tensile properties are obtained by comparing the retained indirect properties of saturated and accelerated water-conditioned laboratory specimens with the similar properties of dry specimens.

2. Apparatus

2.1 Two automatically controlled water baths will be required for immersing the specimens. The baths will be of sufficient size to permit total immersion of the test specimens. They will be so designed and equipped to permit accurate and uniform control of the immersion temperature. One bath is provided for bringing the immersed specimens to the temperature of 140 ± 3.6 F (60 ± 2C) for the warm-water-soak portion of the specimen conditioning. The second bath is provided for bringing the immersed specimens to either the selected test temperature of 55 ± 1.85 F (12.8 ± 1C) or of 73 ± 1.8 F (22.8 ± 1C) for the indirect tensile testing. The baths will be constructed of or lined with stainless steel or other nonreactive material. The water in the baths will be either distilled or otherwise treated to eliminate electrolytes; and the baths will be emptied, cleaned, and refilled with fresh water for each series of tests.

2.2 One automatically controlled freezer will be required for freezing the specimens. The freezer will be of sufficient size to permit total containment of the test specimens. It will be so designed and equipped to permit accurate and uniform control of its air temperature. The freezer is required to bring the specimens to the selected temperature of −0.4 ± 3.6 F (−18 ±2C) for the freeze portion of specimen accelerated conditioning.

2.3 One vacuum pump with capacity to pull at least 26 in. (66 cm) of mercury will be required to water-saturate the test specimens. Accessory equipment will include: Pyrex or equivalent vacuum jars of at least 6 in. (15 cm) diameter and 8 in. (20 cm) high with smooth fired edges, a donut-shaped gasket made of rubber-type sponge, a stiff metal round plate greater than 6 in. (15 cm) diameter with suitable vacuum hose receptacle and hole bored through the plate thickness, vacuum hose attached to receptacle fitting and vacuum pump, and a 6-in. (15-cm) diameter screen-type or highly porous specimen spacer seat approximately 0.25 in. (1 cm) high.

2.4 A compressive testing machine as described in accordance with Method D 1074, but having the controlled deformation rate capability of 0.065 in. per min (0.165 cm per min).

2.5 Mark III or Mark IV Resilient Modulus Apparatus manufactured by Retsina Co., El Cerrito, CA 94530, or equivalent.

2.6 A balance and a room-temperature water bath with suitable accessory equipment will be required for weighing the test specimens in air and in water (saturated specimens only) in order to determine their densities, the amount of absorption, and permeable voids. This apparatus is similar to that required for Method D2762, Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.

2.7 A supply of plastic film for wrapping and heavy-duty leak-proof plastic bags will be required to wrap and enclose the saturated specimens for preventing moisture loss during handling and freezing. Also, several metal jars of at least 4 in. (10.2 cm) diameter and at least 6 in. (15 cm) high will be required for bringing dry specimens to test temperature without water intrusion into the dry specimens in the water bath.

3. Test Specimens

3.1 At least nine, duplicate 4-in. (102-mm) diameter by 2.5-in. (63.5-mm) high cylindrical test specimens of the same mixture will be made for each test. The procedures described

in either Method D1559, Test for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, or Method D1561, Test for Compaction of Test Specimens of Bituminous Mixtures by Means of California Keading Compactor, or Method D3387, Test for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine, will be followed in preparing the loose mixtures and in molding and curing the test specimens.

4. Grouping, Vacuum Saturation, and Determination of Bulk Density and Permeable Voids of Test Specimens

4.1 Allow each set of nine test specimens to cool at room temperature for at least 24 hours after completion of specimen fabrication described in Methods D1559, D1561, and D3387. Label each specimen with waterproof identification and obtain the dry weight of each specimen to the nearest 0.1 g.

4.2 Randomly select a subset, I, of three specimens from the set of nine test specimens. Maintain subset I specimens in a dry condition. Place subset I specimens in metallic jars and then place the jars in a water bath at the selected mechanical test temperature (refer to section 6 for information on the selection of mechanical test temperature) of 55 ± 1.8 F (12.8 ± 1 C) or 73 ± 1.8 F (22.8 ± 1 C) for 5 hours maintaining the top rim of the jars above the water level of the bath. Place an insulating stuffing in the top of the jars, making contact with the top specimen's surface and with the jar walls, then proceed with the mechanical testing of subset I as described in sections 6–9.

4.3 The six remaining test specimens will be vacuum saturated as follows. Place a porous spacer seat on the bottom of a vacuum jar and then place one or more of the specimens, depending on jar height, flat in the jar using another porous spacer seat between the specimens. Put distilled water, or water treated to eliminate electrolytes, at 73 F (22.8 C) in the jar to about 1 in. (2.5 cm) above the upper specimen's surface. Place a dampened donut gasket and a stiff metallic plate on top of the jar. Attach a vacuum hose from vacuum pump. Apply a vacuum of 26 in. (66 cm) of mercury to the jars for a duration of 30 min., gently agitating the jar wall. Remove the vacuum and leave the six specimens submerged in the jars at atmospheric pressure for 30 minutes.

4.4 Remove each of the six specimens from the vacuum jars, quickly surface dry the specimens by towel blotting, and weigh immediately in air and then weigh submerged in room-temperature water at approximately 73 F (22.8 C). Immediately after weighing each submerged specimen, return the specimens to the water-filled vacuum jars and submerge each specimen temporarily under the water at atmospheric pressure.

4.5 Calculate the bulk density and permeable voids of each of the six vacuum-saturated test specimens as follows:

$$\text{Bulk density} = \frac{AD}{B - C} \qquad \text{(A-1)}$$

$$\text{Permeable voids, \%} = \frac{100\,(B - A)}{B - C} \qquad \text{(A-2)}$$

where:

A = weight of dry specimen in air, g;

B = weight of surface-dry (blotted) vacuum-saturated specimen in air, g;

C = weight of vacuum saturated specimen submerged in water, g; and

D = density of water at 73F (22.8C), g/cc.

4.6 Sort and assign each of the six vacuum-saturated test specimens into subsets, II and III, consisting of three specimens each so that the average permeable voids (or average bulk density) is essentially the same in each subset. Immerse subset II specimens into a water bath at the selected mechanical test temperature of 55 ± 1.8 F (12.8 ± 1 C) or 73 ± 1.8 F (22.8 ± 1 C) for 3 hours and then proceed with the mechanical testing of this subset described in sections 6–9. Condition the subset III specimens by using the procedure described in section 5.

5. Accelerated Conditioning Procedure

5.1 Maintain specimen surface dampness and internal saturation, and wrap tightly each of the three specimens of subset III with two layers of plastic film using masking tape to hold the wrapping if necessary. Place each wrapped specimen into a leak-proof plastic bag containing approximately 3 ml of distilled water, and seal the bag with a tie or tape.

5.2 Immerse each of the three individually wrapped and bagged specimens of subset III into an air bath freezer for 15 hours at −0.4 ± 3.6 F (−18 ± 2 C). (If this step begins at 5 p.m., specimens can be removed from the freezer at 8:00 a.m. the following day).

5.3 Remove the three wrapped and bagged specimens of subset III from the freezer and immerse them immediately into a water bath at 140 ± 3.6 F (60 ± 2 C) for 24 hours. (After 3 min of immersion, when specimen surface thaw takes place, rapidly, but carefully, remove the bag and wrapping from the specimens and rapidly reimmerse the specimens in the water bath).

5.4 Carefully remove the three unwrapped specimens of subset III from the water bath, immerse the specimens in a water bath at the selected mechanical test temperature of 55 ± 1.8 F (12.8 ± 1 C) or 73 ± 1.8 F (22.8 ± 1 C) for 3 hours, and proceed with the mechanical testing of this subset as described in sections 6–9.

6. Selection of Mechanical Test Temperature

6.1 The selection of the mechanical test temperature for the nine specimen set is based on the type of mechanical test desired for measurement of the effects of the water-related conditioning. Diametral (tensile) resilient modulus may be performed at either 55 ± 1.8 F (12.8 ± 1 C) or 73 ±1.8 F (22.8 ± 1 C). Diametral tensile strength is performed at 55 ± 1.8 F (12.8 ± 1 C). If low-to-moderate stresses are applied to the specimens in the diametral (tensile) resilient modulus test, this test can be considered nondestructive and the same specimens can be also tested using the diametral tensile strength test, therefor providing additional mechanical properties data. If this is to be done, specimens must be reimmersed in the water bath at selected test temperature for 1 to 2 hours after diametral (tensile) resilient modulus testing prior to the diametral tensile strength testing.

7. Specimen Handling in the Mechanical Testing Procedures

7.1 Each specimen subset shall be tested rapidly following the completion of their respective test-temperature water-bath soak times as prescribed in section 4.2 for subset I, section 4.6 for subset II, and section 5.4 for subset III.

7.2 Remove a subset specimen from the water bath at the test temperature, surface dry by blotting with a towel (necessary for specimens from subsets II and III), measure and record the specimen height (thickness) and identification, and place the specimen with circular ends vertical (specimen on edge) into the appropriate mechanical loading device. Test one specimen at a time, leaving the remaining untested specimens in the water bath. Proceed with testing as rapidly as possible because the mechanical testing will expose the specimen to air temperature which may be different from the test temperature. Test the specimens by either one or both of the procedures described in sections 8 and 9.

8. Test and Calculation Procedure for Diametral (Tensile) Modulus

8.1 Place the transducers of the Resilient Modulus Apparatus on the specimen at test temperature and proceed rapidly with diametral loading at 0.1-sec load duration time, following the procedures described in the instruction manual provided by the manufacturer. Record load and horizontal deformation. Rotate the specimen 90° and repeat.

8.2 Calculate the specimen's diametral resilient modulus for each of the two 90° rotations as follows:

$$M_R = \frac{P(\nu + 0.2734)}{L\Delta} \qquad \text{(A-3)}$$

where:

M_R = diametral resilient modulus, psi (k Pa);
P = load magnitude applied to specimen, lb (N);
ν = Poissons ratio of specimen (use 0.35 unless measured specifically);
0.2734 = dimensionless strain integration constant for 4-in. (10.2-cm) diameter specimens;
L = thickness of specimen, in. (cm); and
Δ = horizontal deformation magnitude of specimen, in. (cm).

The average of the two 90° resilient modulus values is calculated for this specimen and test temperature. Return specimen to water bath if a diametral tensile strength test is also to be performed on the same specimen.

8.3 Repeat by testing the two remaining specimens in the subset, and calculate the overall average diametral resilient modulus for the subset of three specimens.

8.4 Repeat procedure and calculations described in sections 8.1–8.4 for the remaining two subsets of three specimens each.

8.5 Proceed to section 10, Calculation.

9. Test and Calculation Procedure for Diametral Tensile Strength

9.1 Place and center a subset specimen at test temperature under the flat loading head of the compression test machine, and proceed quickly with diametral loading at a vertical deformation rate of 0.065 in. per min (0.165 cm per min). The specimen is placed on its edge without support blocks or loading strips). Record the maximum compressive load. Immediately decrease load to zero, remove specimen and measure specimen edge or side flattening to nearest 0.1 in. (0.25 cm). This can be accomplished easily by stroking the top flattened edge (side) with a piece of chalk held lengthwise to delineate the flattened width and then using a scale to measure the average maximum width of the flattened edge. Record this width.

9.2 Replace the specimen in the compression test machine with its original orientation (flattened edges top and bottom) and redeform the specimen at 0.065 in. per min (0.165 cm per min) until a definitive vertical crack appears and opens. Decrease load to zero, remove specimen, and slowly pull apart the two sides of the specimen at the crack. The internal surface may then be observed for stripping and recorded qualitatively.

9.3 Calculate the specimen's diametral tensile strength as follows:

$$S_t = \frac{S_{10}P}{10{,}000\ L} \qquad \text{(A-4)}$$

where:

S_t = diametral tensile strength, psi (k Pa);
S_{10} = maximum tensile stress, psi (k Pa), obtained by calculating: $1591 + 437a - 1889a^2 + 2854a^3 - 2474a^4 + 885a^5$, where a = flattening width, in., based on a 4 in. (10.2 cm) diameter solid cylinder loaded at 10,000 lb (22 kg) per inch (cm) thickness (note: to calculate S_{10} in SI units, first calculate S_{10} in U.S. customary units of psi using the polynomial constants as shown, with a in inches, then convert psi to k Pa using 1 psi = 6.895 k Pa);
P = maximum compressive load on specimen, lb (N);
10,000 = load constant: 10,000 lb per in. of thickness (17,512 N per cm of thickness); and
L = thickness of specimen, in. (cm).

9.4 Repeat by testing the two remaining specimens in the subset, and calculate the overall average diametral tensile strength for the subset of three specimens.

9.5 Repeat procedure and calculations described in sections 9.1–9.4 for the remaining two subsets of three specimens each.

9.6 Proceed to section 10, Calculation.

10. Calculation

10.1 Calculate the numerical indices of the effects of vacuum saturation and accelerated conditioning as the ratios of the mechanical properties of subsets II and III to the mechanical properties of subset I for the specified test temperature as follows:

$$M_R R_1 = \frac{M_R\,(II)}{M_R\,(I)} \quad \text{and} \quad M_R R_2 = \frac{M_R\,(III)}{M_R\,(I)} \qquad \text{(A-5)}$$

where:

$M_R R_1$ = diametral resilient modulus ratio of saturation;
$M_R R_2$ = diametral resilient modulus ratio of accelerated conditioning;

M_R (I) = average diametral resilient modulus of specimen subset I, psi (k Pa);

M_R (II) = average diametral resilient modulus of specimen subset II, psi (k Pa); and

M_R (III) = average diametral resilient modulus of specimen subset III, psi (k Pa).

$$TSR_1 = \frac{S_t\,(II)}{S_t\,(I)} \text{ and } TSR_2 = \frac{S_t\,(III)}{S_t\,(I)} \qquad \text{(A-6)}$$

where:

TSR_1 = diametral tensile strength ratio of saturation;

TSR_2 = diametral tensile strength ratio of accelerated conditioning;

S_t (I) = average diametral tensile strength of specimen subset I, psi (k Pa);

S_t (II) = average diametral tensile strength of specimen subset II, psi (k Pa); and

S_t (III) = average diametral tensile strength of specimen subset III, psi (k Pa).

Ratios will be reported to the nearest hundredth.

10.2 Ratios may be interpreted as follows. $M_R R_1$ and TSR_1 are related to short-term pavement performance (e.g., 2–4 yr), and $M_R R_2$ and TSR_2 are related to long-term pavement performance (e.g., 4 yr or more). Low ratios are associated with the mixture's inability to resist moisture effects.

11. Single-Operator Precision

11.1 The single operator standard deviation has been found to be 14 percent for $M_R R$ and 10 percent for TSR. (These numbers represent, respectively, the (IS) and (D2S) limits as described in ASTM Recommended Practice C 670, for Preparing Precision Statements for Test Methods for Construction Materials.) Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 40 percent for $M_R R$ and 28 percent for TSR.

NCHRP 274

METHOD OF TEST FOR DETERMINING THE EFFECT OF MOISTURE AND ANTISTRIPPING ADDITIVES ON ASPHALT CONCRETE PAVING MIXTURES

1. Scope

This method contains procedures for preparing and testing specimens of asphaltic concrete for purposes of measuring the effect of water, or the effectiveness of antistripping additives on the tensile strength of the paving mixture. The method is applicable to dense mixtures such as those appearing in the upper half of Table 3, ASTM Specification D 3515. The method can evaluate the effect of moisture with or without additives, the effect of liquid antistripping additives which are added to the asphalt cement, or pulverulent solids such as hydrated lime or portland cement which are added to the mineral aggregate.

2. Applicable Documents

2.1. ASTM Standards

- D 979 Method for Sampling Bituminous Paving Mixtures
- D 1559 Test for Resistance to Plastic Flow of Bituminous Mixtures by Marshall Apparatus
- D 2041 Test for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
- D 2726 Test for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
- D 3203 Test for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
- D 3515 Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures
- D 3549 Test for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 3665 Practice for Random Sampling of Construction Materials
- D 4123 Method of Indirect Tensile Test for Resilient Modulus of Bituminous Mixtures

3. Significance and Use

This method can be used to test asphaltic concrete mixtures in conjunction with mixture design testing to determine whether or not moisture damage is severe enough so that an additive should be considered, and if it is severe enough, to determine whether or not an antistripping additive is effective and what dose of additive is most effective. It can also be used to test mixtures produced at plants to determine the severity of moisture damage and the effectiveness of additives under conditions imposed by construction in the field. Finally, it can be used to test cores from completed pavements of any age to determine the severity of moisture damage and the effectiveness of additives under conditions of exposure and service in the field.

4. Summary of Method

4.1. To determine the severity of moisture damage and decide whether or not an additive should be considered, a set of laboratory-compacted specimens conforming to the job-mix formula without additive is prepared. The specimens are compacted to a void content corresponding to void levels expected in the field, usually in the 6 to 8 percent range. The set is divided into two subsets of approximately equal void content, and one subset is maintained dry, while the other subset is saturated with water and moisture conditioned. The tensile strength of each subset is determined by the tensile splitting test. The severity of moisture damage is indicated by the ratio of the tensile strength of the wet subset to that of the dry subset.

4.2. To determine the effectiveness of an antistripping additive a set of specimens containing additive but otherwise the same as the set in Section 4.1 is prepared and tested, and the severity of the moisture damage is determined in the manner described in Section 4.1. The effectiveness of the additive is indicated by the improvement in the wet-to-dry ratio of the set containing additive compared to the set without additive. The effect of additive dosage may be estimated by repeating the set with different additive dosages.

4.3. To determine the severity of moisture damage or the effectiveness of an additive in mixture produced in an asphalt plant in the field, specimens are laboratory compacted to field level void content, divided into wet and dry subsets, and the severity of moisture damage or the effectiveness of the additive is determined as in Section 4.2.

4.4 To determine the severity of moisture damage or the effectiveness of an additive in specimens cored from a pavement, cores are maintained at in-place moisture content until tensile strength is measured. This strength may be compared to the tensile strength determined previously before moisture damage occurred.

5. Apparatus

5.1. Equipment for preparing and compacting specimens from Method D 4123.

5.2. Vacuum pump or water aspirator, manometer or vacuum gauge, and container, preferably Type D, from Method D 2041.

5.3. Balance and water bath from Method D 2726.

5.4. Water bath or oven capable of maintaining a temperature of 140 F for 24 hours.

5.5. Loading jack and ring dynamometer from Method D 1559, or a mechanical or hydraulic testing machine capable of maintaining the required strain rate and measuring load with suitable precision.

5.6. Loading strips from Method D 4123.

6. Preparation of Laboratory Test Specimens

6.1. At least six specimens shall be made for each test, three to be tested dry and three to be tested after saturation and moisture conditioning.

6.2. Specimens 4 in. in diameter and 2.5 in. thick are usually used. Specimens of other dimensions may be used if desired and should be used if aggregate larger than 1 in. is present.

6.3. When 4-in. × 2.5-in. specimens are used, mixtures shall be prepared in batches large enough to make at least 3 specimens. When larger specimens are used, batches may be prepared for each specimen. If theoretical maximum specific gravity is to be determined, the batch should be large enough to provide the specimen for that purpose also.

6.4. When a liquid antistripping additive is used, the asphalt cement in sufficient quantity for one batch shall be heated to 300 F in a closed one quart can in an oven. The required quantity of additive shall be added. Immediately lower a mechanical strirrer to within 1 in. of the bottom of the container, and mix the contents for 2 min. Maintain the treated asphalt cement at 300 F in the closed can until it is used. If the treated asphalt cement is not used on the same day in which it is prepared, or if it is allowed to cool so that it would require reheating, it shall be discarded.

6.5. When a pulverulent solid antistripping additive is used, the batch of mineral aggregate shall be dried, composited, and heated to 300 F. The required quantity of additive shall be added to the aggregate, and the entire mass shall be thoroughly mixed until a uniform distribution of additive has been achieved. Care

shall be taken to minimize loss of additive to the atmosphere in the form of dust. After mixing, maintain the treated aggregate at the temperature required for mixing until it is used.

6.6. Proportion, mix, and compact specimens in accordance with Method D 4123 and Sections 6.6.1 and 6.6.2.

6.6.1. After mixing, stabilize mixture temperature at the required compaction temperature in a closed container in an oven for from 1 to 2 hours.

6.6.2. Compact specimens to 7 ± 1 percent air voids, or a void level expected in the field. This level of voids can be obtained by adjusting the static load in double plunger compaction; the number of blows in Marshall hammer compaction; the foot pressure, number of tamps, leveling load, or some combination in kneading compaction; or the number of revolutions in gyratory compaction. The exact procedure must be determined by trial for each mixture.

6.6.3. Cool specimens to room temperature as rapidly as possible in a stream of moving air, extract from molds, and proceed with Section 9 immediately if possible, but within 24 hours at most.

7. Preparation of Field Specimens

7.1. Select a truck to be sampled in accordance with Practice D 3665.

7.2. Secure a sample from the truck at the plant in accordance with Method D 979.

7.3. Stabilize mixture temperature to approximately the temperature found in the field when rolling begins. Maintain this temperature in a closed container, in an oven if necessary, for approximately the time lapse between mixing and the start of actual rolling.

7.4. Compact specimens in accordance with Section 6.6.2. and cool and extract from molds in accordance with Section 6.6.3.

7.5. If specimens are not to be compacted in the field laboratory, place the samples in a sealed container, transport to the laboratory, and reheat to the temperature required in Section 7.3. Then proceed with Section 7.4.

8. Preparation of Core Test Specimens.

8.1. Select locations to be sampled on the completed pavement or pavement layer in accordance with Practice D 3665.

8.2. Core at the selected locations in accordance with Method D 979. A wet coring process should be used, and the periphery of the core should be blotted dry immediately after it is taken. Wrap the core in plastic wrap or otherwise protect it to maintain field moisture content until the test layer of the core is separated.

8.3. Separate core layers as necessary by sawing or other suitable means. A wet sawing process is preferred, and the periphery of the test layer of the core should be blotted dry immediately after it is sawn. Wrap the test layer in plastic wrap or otherwise protect it to maintain field moisture content until it is tested.

9. Procedure

9.1. Determine the theoretical maximum specific gravity by Method D 2041.

9.2. Determine specimen thickness by Method D 3549.

9.3. Determine the bulk specific gravity by Method D 2726, and express the volume of the specimen in cubic centimeters. The term (B-C) in Method D 2726 is the volume of the specimen in cubic centimeters.

9.4. Calculate air voids by Method 3203, and express the volume of air in cubic centimeters. The volume of air is the volume of the specimen from Section 9.3 multiplied by the percentage air voids.

9.5. Sort specimens into two subsets so that average air voids of the two subsets are approximately equal. Store the subset to be tested dry at room temperature.

9.6. Saturate the subset to be moisture conditioned with distilled water at room temperature. If it is difficult to reach the minimum degree of saturation of 55 percent required in Section 9.6.3, the water used to saturate may be heated up to 140 F.

9.6.1. Saturate by applying a partial vacuum such as 20 in. Hg for a short time such as 5 min.

Note 1: Experiments with partial vacuum at room temperature indicate that degree of saturation is very sensitive to the magnitude of the vacuum and practically independent of the duration. The level of vacuum needed appears to be different for different mixtures.

9.6.2. Determine bulk specific gravity by Method D 2726. Determine the volume of absorbed water by subtracting the air dry weight of the specimen found in Section 9.3 from the saturated surface dry weight of the saturated specimen found in Section 9.6.2.

9.6.3. Determine the degree of saturation by dividing the volume of absorbed water found in Section 9.6.2 by the volume of air voids found in Section 9.4 and expressing the result as a percentage. If the volume of water is between 55 and 80 percent of the volume of air, proceed to Section 9.7. If the volume of water is less than 55 percent, repeat the procedure beginning with Section 9.6.1 using a slightly higher partial vacuum. If the volume of water is more than 80 percent, the specimen has been damaged and is discarded.

Note 2: If the average air voids of the saturated subset is less than 6.5 percent, saturation of at least 70 percent is recommended.

9.7. Moisture-condition the saturated specimens by soaking in distilled water at 140 F for 24 hours.

9.8. Adjust the temperature of the moisture-conditioned subset by soaking in a water bath for 1 hour at 77 F.

9.9. On moisture-conditioned subset, measure thickness by Method D 3549, and determine bulk specific gravity by Method D 2726.

9.9.1. Determine water absorption and degree of saturation in accordance with Section 9.6.2 and Section 9.6.3. Saturation exceeding 80 percent is acceptable in this step.

9.9.2. Determine swell of saturated specimens by dividing the change in specimen volumes found in Sections 9.6.2 and 9.3 by the specimen volume found in Section 9.3. Determine swell of conditioned specimens by dividing the change in specimen volumes found in Sections 9.9 and 9.3 by the specimen volume found in Section 9.3.

9.10. Adjust temperature of dry subset by soaking in a water bath for 20 min at 77 F.

9.11. Determine tensile strength at 77 F of both subsets.

9.11.1. Apply diametral load in accordance with Method D 4123 at 2.0 in. per minute until the maximum load is reached, and record the maximum load.

9.11.2. Continue loading until specimen fractures. Break open and estimate and record stripping, if any.

9.11.3. Inspect all surfaces, including the failed faces, for evidence of cracked or broken aggregate, and record observations.

10. Calculations

10.1. Tensile Strength

$$S_t = 2P/\pi tD$$

where:

S_t = tensile strength, psi;
P = maximum load, lb;
t = specimen thickness immediately before tensile test, in.; and
D = specimen diameter, in.

10.2. Tensile Strength Ratio

$$TSR = (S_{tm}/S_{td})100$$

where:

TSR = tensile strength ratio, percent;
S_{tm} = average tensile strength of moisture-conditioned subset, psi; and
S_{td} = average tensile strength of dry subset, psi.

11. Report

11.1. Average room temperature at which any measurements are made.

11.2. Number of specimens in each subset.

11.3. Average degree of saturation after saturating and after moisture conditioning.

11.4. Average swell after saturating and after moisture conditioning.

11.5. Tensile strength of each specimen in each subset.

11.6. Tensile strength ratio.

11.7. Results of estimated stripping observed when specimen fractures.

11.8. Results of observations of fractured or crushed aggregate.

12. Precision

12.1. Precision of the method is under study.

12.2. Tests on one moisture-conditioned mixture containing additive in one laboratory indicate that the difference in tensile strength between duplicate specimens should not exceed 25.2 psi.